El Niño/Southern Oscillation Events and Their Associated Midlatitude Teleconnections 1531–1841

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Abstract

This paper reports on an investigation into the chronology of El Niño/Southern Oscillation (ENSO) events during the period from the arrival of Europeans in Peru in 1531 until the year 1841 when conventional barometric data became available in the tropical regions. A number of probable ENSO events can be dated from anecdotal reports of significant rainfall in the coastal desert of northern Peru. In many of the years with anomalous Peruvian rainfall it is also possible to use various types of proxy data to identify aspects of the global teleconnection patterns usually associated with tropical ENSO events.

1. Introduction

Studies of the Southern Oscillation, the El Niño phenomenon and their associated effects throughout the global atmosphere have proliferated over the last two decades (see Cane, 1983, and Rasmusson and Wallace, 1983, for recent reviews). Observational investigations have largely concentrated on fairly recent periods with relatively abundant data. Naturally enough, curiosity has also developed about the chronology of El Niño/Southern Oscillation (ENSO) events in the more-distant past. A number of recent papers have addressed this issue or have proposed methods to do so. Quinn et al. (1978) employed various types of data from the tropical Pacific region (barometric pressure, rainfall and sea-surface-temperature measurements) to construct a chronology of ENSO events back to 1841. None of the records of conventional data used by Quinn et al. exists before 1841. However, Quinn et al. did date some probable ENSO years back to 1726 from anecdotal reports of significant rainfall in the normally dry coastal areas of northern Peru.

Another group of investigations has dealt with ways of using biological and geological objects, such as corals, glacial ice, and ocean-bottom cores to establish the chronology of ENSO events. Thompson et al. (1984) observed that cores taken from the Quelccaya ice cap in Peru showed that the annual snow accumulation is suppressed during major ENSO events. They actually correlated their ice-core data with the known occurrences of ENSO only over the last two decades, but they note that their approach might be employed to help establish the dates of major ENSO events as early as 1500 years before the present.

Schrader and Pisias (1985) have examined the microfloral composition of cores of varved sediments from the Guaymas Basin. They determined that the presence of certain microfloral assemblages in their cores could be related to the occurrence of major ENSO events. This kind of analysis would appear to have the potential for providing information concerning the ENSO phenomenon over some thousands of years.

Shen and Boyle (1984) have shown that the chemical composition of the annual growth rings of coral skeletons from the Galapagos Islands is anomalous in major ENSO years. In particular, the cadmium concentration in the coral shells is observed to be reduced in ENSO years. These anomalies presumably reflect changes in the ocean chemistry caused by the suppression of equatorial upwelling during ENSO events. Shen and Boyle have applied their analysis only for the last two decades, but their technique does have the potential for unveiling the history of equatorial upwelling in the more distant past.

A somewhat different approach to inferring the chronology of ENSO events has been discussed recently by Lough and Fritts (1985). They correlated time series of measured ring widths from a large number of trees in the extratropical regions of both hemispheres with an observed index of the Southern Oscillation based on tropical barometric measurements during the period 1853–1961. They then applied these results to earlier tree-ring data to infer the Southern Oscillation index in each year from 1600. By itself such a method cannot produce a perfectly reliable chronology of low-index years (corresponding to ENSO events) since the midlatitude circulation patterns are not observed to take precisely the same form during each individual tropical ENSO event (e.g., Dickson and Livezey, 1984; Emery and Hamilton, 1985; Yarnal and Diaz, 1986).

The present paper extends the work of Quinn et al. (1978) by presenting a more-complete survey of the historical sources concerned with Peruvian rainfall. The resulting chronology of ENSO events is then compared with various types of proxy data to determine if there are hints of the usual anomalous global-scale weather patterns during the individual tropical events. The present study provides benchmarks for comparison with the results that will be obtained with the various geochemical techniques as they are applied to the more-distant past.

2. Peruvian rainfall

Perhaps the most dramatic local meteorological manifestation of ENSO events are the February–April rain showers in

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TABLE 1. Comparison of March–April rainfall in 1965 with the mean for the period 1960–64 and 1966–69 at selected localities along the west coast of Peru. Also shown is the ratio of the 1965 March–April rainfall to the normal value.

Station	Latitude	1965 Rainfall (mm)	Normal Rainfall (mm)	Ratio
Piura	5.2°S	76	4	19.0
Chiclayo	6.8°S	73	4	18.3
Chimbote	9.2°S	17	2	8.5

the coastal desert of northern Peru. Under ordinary conditions the coastal plains of Peru are remarkable for the almost complete absence of rainfall (e.g., Sears, 1895; Murphy, 1926; Schweigger, 1959). However, this normal pattern alters during the onset phase of a significant ENSO event in the February–April period. In some cases there are modest rain showers (but still much greater precipitation than normal), while in very strong ENSO events there can be torrential downpours. An example of the effects of a typical ENSO event is presented in Table 1 which compares the rainfall in

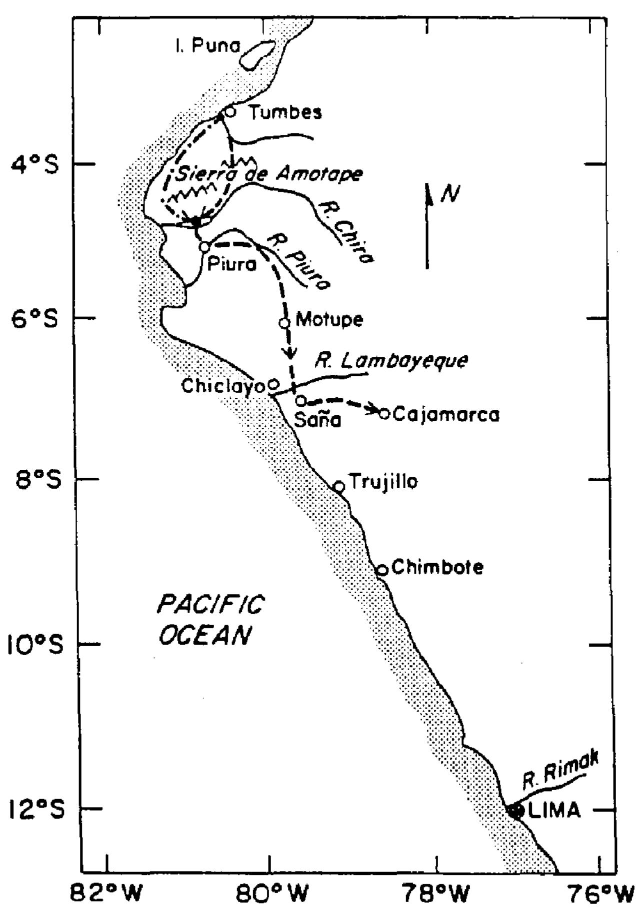

FIG. 1. Map of Peruvian coast showing localities mentioned in the text. The dash-dot arrows show the approximate route of Pizarro's march to Cajamarca in May–November 1532 taken from Cohen (1968). The dashed arrows show Pizarro's route according to Raimondi (1876). The solid dot on the Chira River shows the approximate location of the original settlement of San Miguel. The town was later moved to a site on the Piura River, and was called San Miguel de Piura, or simply Piura.

March and April during the onset of the 1965 ENSO event (classed as "moderate" in strength by Quinn et al., 1978) with the mean during the "normal" years 1960–64 and 1966–69 (see Fig. 1 for the location of the stations considered). Murphy (1926) presents data for the rainfall at Trujillo in March 1925, during the onset phase of the very strong 1925–26 ENSO event. He compares this with rainfall measured in some preceding years (see his tables 9 and 10). In the single month of March 1925, 394.4 mm of rain fell (over 200 mm in three days), while in the preceding five-year period (1920–24) Trujillo received a total of only 17.9 mm of precipitation. Similar torrential rains occurred in the coastal plains of northern Peru during the onset of the 1891–92 ENSO event (Murphy, 1926).

The effects of the rains when they do come to this normally dry region are quite spectacular. Flowers and other forms of plant life normally absent suddenly flourish among the xerophilous desert vegetation (e.g., Sears, 1895; Murphy, 1926). The production and extension of lakes and ponds in the desert region can even result in malaria outbreaks (Murphy, 1926). The coastal rains are generally restricted to the northern part of Peru; at the latitude of Lima (Fig. 1) it is very unusual to receive heavy rainfall even during a major ENSO event (this can be verified in the Lima rainfall data reported in Clayton and Clayton, 1947; U.S. Department of Commerce, 1959, 1966). However, the effects of the rains accompanying an ENSO event can cause the level of the Rimak River (Fig. 1) to rise, affecting agricultural activities in the Rimak valley and even causing flooding in Lima itself (Murphy, 1926). In the north, the bed of the Piura River (Fig. 1) is generally dry much of the year (from at least July through December) but this river can actually be in flood after the onset of a major ENSO event (Murphy, 1926), and in an ENSO year the water may flow as late as November (Sears, 1895).

Throughout the remainder of this article a tacit assumption will be made that very heavy rainfall in the coastal desert of northern Peru can be taken as an indication of the onset of an ENSO event (i.e., that the rains are roughly coincident with a change in sign of the usual Southern Oscillation pressure index). This is consistent with the standard view of the role normally played by the El Niño phenomenon in each cycle of the Southern Oscillation (e.g., Rasmusson and Carpenter, 1982), and was also the basis of the approach adopted by Quinn et al. (1978) to date ENSO events in the distant past. However, in the absence of any direct information concerning the Southern Oscillation index prior to 1841, the list of heavy-rain years discussed below should be regarded as a chronology of *probable* onset years of ENSO events.

Given the rare occurrence and important effects of the rains in the Peruvian coastal desert, it is reasonable to expect that at least some of the major rainy seasons would be recorded in local publications. The first systematic attempt to review the relevant literature appears to be that of Eguigúren (1894a), who begins by quoting early historians of Peru to demonstrate that the remarkable dryness of the coastal plains has been the prevailing condition at least since the arrival of Europeans in the sixteenth century. He then surveys various published sources to document deviations from the normal pattern.

One of the earliest records of unusual rainfall and flood conditions is provided by the famous *Historia del Nuevo Mundo*, completed in 1652 by the Jesuit father and historian Bernabé Cobo. Cobo (as quoted by Eguigúren, 1894a) refers to flooding in Lima in 1541 and flooding near Lima in 1614. In February 1652 flooding in Lima became so severe that the bishop asked the people to pray for a cessation of the rains. Cobo also notes that heavy rainfall occurred in the diocese of Trujillo in north-central Peru in both 1578 and 1624. The rains in 1578 are also mentioned by another Jesuit, Father José de Acosta, in his *Historia Natural y Moral de las Indias* written near the end of the sixteenth century (Acosta, 1894). While remarking on the dryness of the coastal plain, Acosta states that "it has rained in certain years when the winds have run from the North . . . as was the case in the year of 1578 on the plains of Trujillo, when large amounts of rain fell, something that had not been seen in a very long time."

Another important source for information concerning rainfall in the coastal plains of Peru comes from the report on the city of Trujillo and the surrounding province prepared for the Spanish crown by Miguel Feyjóo de Sosa and published in Madrid in 1763 (Feyjóo de Sosa, 1763). This author devotes an entire chapter of his work to the rainfall in the region. He describes the normally dry conditions and notes four exceptions earlier in the century, 1701, 1720, 1728, and 1747. The rains in 1728 are said to have been so great that "rivers of water ran through the streets and plazas" of Trujillo. The rainfall in 1747 was not noted by Eguigúren (1894a) or by Quinn (1978). Concerning this year Feyjóo de Sosa remarks that it rained in Trujillo "on two occasions, for a space of several hours," and that "dense clouds were seen to the South, where they discharged their rain."

Another interesting comment appears in Feyjóo de Sosa's work. He discounts an earlier report of strong rains in Trujillo in 1726 made by Jorge Juan and Antonio de Ulloa in their 1748 publication *Relacion Historica del Viaje a la América Meridional*. Feyjóo de Sosa claims that the rains discussed by Juan and Ulloa actually were those that fell in 1728, and that this is "attested to by many trustworthy witnesses . . . and by public documents and papers that refer to this disaster." It is also noteworthy that Eguigúren (1894a) does not mention the 1726 rain, although he does make other references to the work of Juan and Ulloa. On balance it was felt advisable to omit the year 1726 from the present chronology of probable ENSO events (although 1726 *is* included by Quinn et al., 1978).

The rains in northern Peru in 1701 and 1720 were also mentioned in the writings of the Bohemian naturalist Tadeo Haenke who was commissioned in the late eighteenth century by the Spanish government to survey parts of South America (Haenke, 1901). Concerning the 1720 rains—while describing the *partidos* (districts) of Saña and Lambayeque—he states that "in the year 1720 there were great rains in those valleys, while at the same time the wind blew with great force, alternating between northwesterly and southerly."

For the interval between 1760 and 1790 there are reports of strong rains in northern Peru in 1763 and 1770 by Frijlinck (1925). This author also gives 1728, 1791, 1804, 1814 and 1828 as rainy years. Frijlinck does not specify the actual sources he employed in the construction of his chronology. 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.

Each year after 1790 is classified by Eguigúren (1894a) according to a qualitative estimate of the rainfall in the province around Piura. This classification is subjective and Eguigúren cautions that "Naturally, the information we have collected contains more or less vague indications (as to the strength of rainfall) . . . years are said to be dry, or very dry . . . or to have had slight rains . . . or normal . . . or copious rains." In his scheme 1791, 1804, 1814, and 1828 (as well as a number of later dates) are classed as years of "extraordinary" rainfall. Quinn et al. (1978) felt that this extraordinary rainfall category would be a reasonable indication of the occurrence of a "strong" ENSO event. Thus these four years have been included in the present chronology of major ENSO events (these four years are also the only ones mentioned during this period by Frijlinck, 1925).

There remains one very interesting possibility for identifying the occurrence of an ENSO event in the historical record. Sears (1895) suggested that the celebrated march of Francisco Pizarro and the Spanish *conquistadores* in 1532 from Tumbes on the coast to Cajamarca (where the Inca Emperor Atahualpa was captured) could only have occurred during a year of abundant rainfall. This issue is discussed in the Appendix, where it is shown that the available evidence is far from conclusive. On balance, it was decided not to include 1532 in the present chronology of ENSO years.

On the basis of the above discussion 1541, 1578, 1614, 1624, 1652, 1701, 1720, 1728, 1747, 1763, 1770, 1791, 1804, 1814, and 1828 are identified as probable years of the onset of major ENSO events. They are *major* events in the sense that their local effects in Peru were strong enough to be recorded, and are generally connected with heavy rainfall or damaging flooding. This suggests that most of them should be regarded as being of comparable intensity to some of the very strong ENSO events in the modern period (such as those beginning in 1891, 1925, and 1982). It should also be clear from the present discussion that errors are possible in the dating of some of the events. Given the limited sources consulted, there are almost certainly significant omissions from the present list. Conceivably a more-complete chronology could be constructed if manuscript sources in Peru or Spain were to be consulted.

3. Extratropical effects revealed in proxy data

Analysis of many types of extratropical meteorological data has revealed significant correlations with the phase of the Southern Oscillation (e.g., Horel and Wallace, 1981; Trenberth and Paolino, 1981; van Loon and Madden, 1981, Pan and Oort, 1983). Fig. 2a (from van Loon and Madden, 1981) shows the correlation of winter surface air temperature over the Northern Hemisphere with the sea-level pressure at Cocos Island (12°S, 96°E), north of Australia. Since the Cocos Island sea-level pressure rises during the onset of an ENSO event, areas of positive correlation in Fig. 2a can be expected (on average) to be anomalously warm in the winter following the onset of a tropical ENSO event (i.e., during the *mature* phase of the event, using the terminology of Rasmusson and Carpenter, 1982). Fig. 2b (also from van Loon and Madden, 1981) shows similar correlations with Northern Hemisphere sea-level pressure. The correlations in Fig 2 are statistically significant over large regions of the extratropics However, the largest correlation coefficients are typically about 0.5. This suggests that at most one quarter of the interannual variance in extratropical surface temperature and pressure can be accounted for by a linear regression with a measure of the Southern Oscillation. In fact, the correlation patterns in Fig. 2 emerge clearly only from data spanning several cycles of the Southern Oscillation, and the usual extratropical signal associated with the mature phase of ENSO events is not observed in each individual event (Emery and Hamilton, 1985; Yarnal and Diaz, 1986)

For roughly the last half of the period considered in this paper there are some instrumental temperature data from central England (Manley, 1974). Some shorter instrumental records are available from other locations in western Europe. Unfortunately, the tropical Pacific/midlatitude teleconnection is rather weak in Europe (Fig. 2). Areas where the atmospheric circulation is more strongly correlated with the Southern Oscillation would include Japan, North America, and even Iceland. The instrumental records from these regions are naturally very limited in the pre-1829 period of present interest. However, there are some types of proxy data that can provide an indication of weather conditions in these areas during the winters in the distant past. Four records of such data that can shed light on the possible extratropical teleconnections of the ENSO events identified in the present investigation are discussed below.

a. Lake Suwa freezing dates

Arakawa (1954) presented a long time series (1443–1954) of dates for the freezing of the surface of Lake Suwa in central Japan (36°N, 138°E; about 150 km west of Tokyo). In the early part of this period the records were apparently kept by a religious shrine In addition to the date of freezing, there are also records of the date of the first ruptures in the ice surface (which usually occur a few days after the lake freezes: see Table 1 of Arakawa, 1954). Over parts of the seventeenth, eighteenth, and nineteenth centuries only the rupture dates are available. The occurrence of anomalously late (early) freezing dates might be expected to indicate anomalously warm (cold) weather in central Japan over some extended period before the lake freezes (generally in January). For present purposes it is useful to note that Gray (1974) has shown that the Lake Suwa freezing dates in the modern (1876–1954) period have correlated reasonably well with both December–January and December–February mean air temperatures at Tokyo.

The results plotted in Fig. 2a suggest that central Japan should generally be warmer than normal during the mature phase of a tropical ENSO event The freezing (or rupture) dates in the winters corresponding to the mature phase of each of the ENSO events identified in Section 2 are given in Table 2. Also shown in this table are the 13-year running means of the dates (i.e. an average over two or three South-

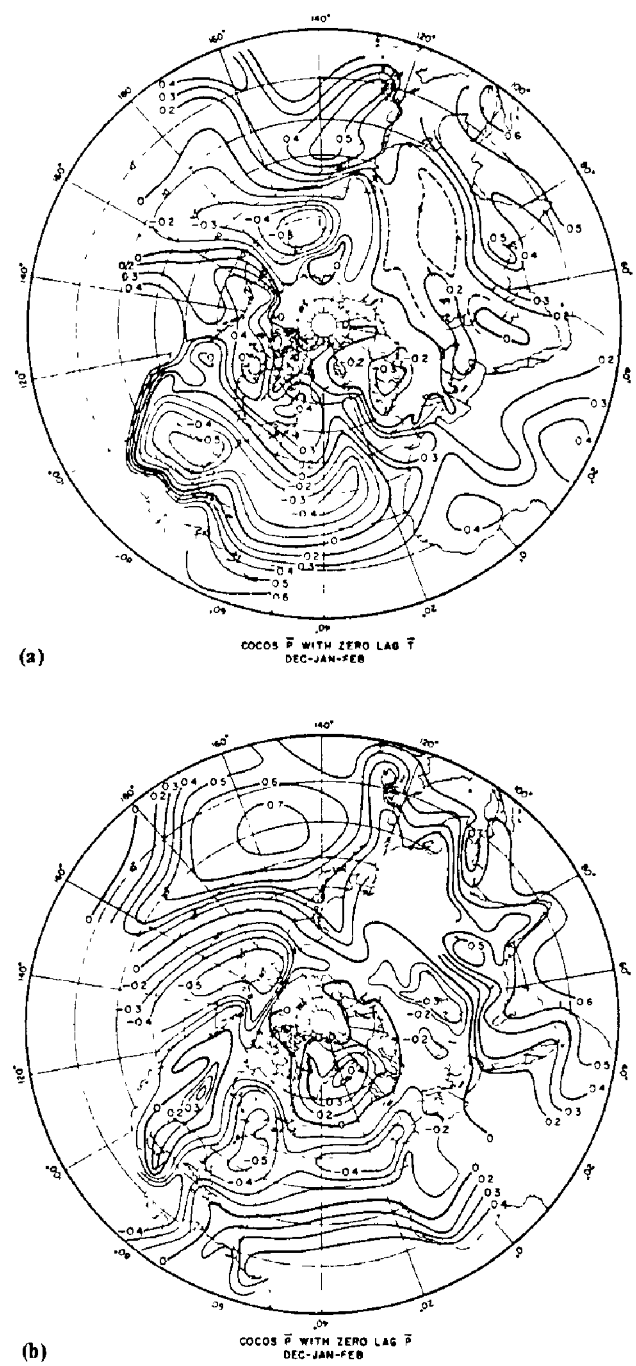

FIG. 2. (a) Correlation coefficients between the December–February sea-level pressure at Cocos Island (12°S, 96°E) and surface air temperature throughout the Northern Hemisphere. Regions of positive correlation are shaded Based on data from the period 1952–1978. Reproduced from van Loon and Madden (1981). (b) As in a, but for correlations with Northern Hemisphere sea-level pressure

ern Oscillation cycles) and an "anomaly" defined as the difference between the individual yearly date and the 13-year mean. This anomaly is positive in nine of the 13 years for which data is available, indicating a tendency for later-than-normal freezing of the lake. The mean and standard deviation of the anomaly values are given at the bottom of Table 2. The mean anomaly is 10 days and the standard deviation of the N values divided by $\sqrt{N-1}$ is 3.58. Defining a t-test statistic as the ratio of these two numbers, one obtains a value of 2.79, which indicates that the mean anomaly is significantly different from zero at the 98 percent confidence level.

b. Tokyo snowfall

Another indication of winter conditions in central Japan is provided by the record of the date of the earliest "snow covering" of Tokyo given by Arakawa (1956). The data he presents extend back to 1632, but with a great many gaps in the record. Arakawa states (without further details) that "studies of various data indicate that snowfalls in winter are a good indicator of a severe or mild winter. It is evident that the dates of the earliest snow covering give, to some extent, a record of winter severity in the region."

Arakawa's dates are given in Table 3 for each of the winters following the onset of ENSO events identified above. The large gaps in the record do not allow the computation of running means to compare with the yearly values, so the anomaly given in this table is the difference between the individual yearly date and the mean date for all available years between 1720 and 1827. It can be seen that the first snow covering came late in five of the seven winters considered, and that over all seven winters the mean date was 6.5 days later than normal. This again is consistent with winters in central Japan being generally warmer than average during the mature phase of ENSO events. However, it should be noted that the t-test statistic for this very small sample is only 1.27 (i.e., there is about a 20 percent chance that such a value could arise from sampling a distribution with zero mean).

c. Freezing and breakup of an estuary on James Bay

Moodie and Catchpole (1975, 1976) have examined the records of the Hudson's Bay Company to determine the dates of formation and breakup of surface ice on estuaries along Hudson Bay and James Bay in central Canada during the eighteenth and nineteenth centuries. The longest time series in their work is for Fort Albany (52°N, 81.5°W) on the western shore of James Bay, for which data is available from 1722 through 1865. Unfortunately there are no modern determinations of comparable dates for freezing and breakup of the Hudson Bay and James Bay estuaries, but it is reasonable to suppose that late (early) freezing and early (late) breakup would be indicators of relatively warm (cold) winters (see McKay, 1952). The modern results shown in Fig. 2a suggest that average conditions during the mature phase of ENSO events in this part of Canada should be anomalously warm (see also Table 4 of Horel and Wallace, 1981).

Table 4 shows the duration of the period between the first recorded freezing of the surface of the Fort Albany estuary in the autumn and the first breaking of the ice surface in the spring for each individual ENSO event. The 13-year running

TABLE 2. Freezing dates of Lake Suwa in central Japan. Dates in individual winters are compared with 13-year running means. After 1700 the dates quoted are for the first recorded ruptures of the ice surface. Dates are in days after 31 December (Gregorian calendar). For the computation of the anomaly the "freezing dates" of the years when the lake did not freeze were taken to be 46 (i.e., 15 February). Based on data given by Arakawa (1954).

Winter	Freezing Date	13-Year Mean	Anomaly
1541–42	3	10.7	−7.7
1578–79	28	10.6	17.4
1614–15	10	3.2	7.8
1624–25	22	6.8	15.2
1652–53	6	10.5	−4.5
1701–02	42	16.1	25.9
1728–29	25	16.8	8.2
1747–48	32	16.8	15.2
1763–63	14	17.2	−3.2
1770–71	did not freeze	17.9	28.1
1791–92	no data		
1804–05	did not freeze	17.5	28.5
1814–15	8	13.1	−5.1
1828–29	21	16.5	4.5
Mean anomaly			10.0
Standard deviation			12.4

TABLE 3. The earliest snow covering of Edo (now Tokyo) in individual winters. Dates are in days after 31 December (Gregorian calendar). The mean date for all available years from 1720–1827 is 6.2, and the anomaly is defined as the difference between the date in an individual winter and this long-term mean. The data is from Arakawa (1956).

Winter	Date of Snow	Anomaly
1720–21	14	7.8
1728–29	17	10.8
1747–48	16	9.8
1763–64	25	18.8
1770–71	4	−2.2
1791–92	26	19.8
1814–15	−13	−19.2
1828–29	no data	
Mean anomaly		6.5
Standard deviation		12.5

TABLE 4. The duration of the period from the first day the estuary at Fort Albany was first recorded as being "partly frozen" in the autumn to the day of the first recorded break in the ice cover in the spring. Results for individual winters are compared with 13-year running means. Based on data from Moodie and Catchpole (1975).

Winter	Duration (days)	13-Year Mean	Anomaly
1728–29	183	191.4	−8.4
1747–48	171	191.4	−20.4
1763–64	172	193.0	−21.0
1770–71	208	192.7	15.3
1791–92	192	178.6	13.4
1804–05	153	183.7	−30.7
1814–15	179	183.7	−4.7
1828–29	201	194.7	7.3
Mean anomaly			−6.2
Standard deviation			16.0

means and anomalies are also reported in the same manner as Table 2. In five of the eight available examples the duration of the ice was anomalously brief during the ENSO winter, and the average duration over all eight winters was six days less than normal. These results are at least suggestive of a relationship between ENSO events and anomalously warm winters in central Canada (although the results fall far short of the usual standards of statistical significance, when judged with a t-test).

d. Ice along the coast of Iceland

Under appropriate conditions drift ice can collect along the north coast of Iceland and can even fill up the passage between Iceland and Greenland. The occurrence of "heavy" ice conditions in an individual year appears to be related to a weakening of the Icelandic low (Bjornsson, 1969) The observations displayed in Fig. 2b suggest that on average the Icelandic low ought to be anomalously weak during the mature phase of ENSO events.

Table 5 shows the duration of drift ice along the coast of Iceland in individual ENSO winters determined from surveys of the local literature by Koch (1945) and Thorarinsson (1956). These are compared with 13-year running means of the ice duration. In this data there may be at least an indication of a tendency for heavier ice conditions following the onset of ENSO events. In fact some of the very heaviest ice years on record (1614–15, 1624–25, 1728–29, 1791–92, and 1828–29) are coincident with probable ENSO events. The years in Table 5 with less than normal ice duration all turn out to be years with no ice reports at all (which may reflect gaps in the literature rather than actual ice conditions).

e. Summary

The rather unusual data described above do provide tantalizing glimpses of a teleconnection between the tropical Pacific and the extratropical atmosphere, similar to that which has been documented with modern data. However, the actual effects revealed in the proxy data are not particularly strong (only the results for Lake Suwa are statistically significant) and are not present for each individual event. The lack of a typical midlatitude signal during some ENSO events is consistent with the results of studies using modern data (Emery and Hamilton, 1985; Yarnal and Diaz, 1986).

It is possible that other kinds of historical data could be compared with the present ENSO chronology. For example, it is known that rainfall in South Africa is often anomalously heavy in the Austral winter following the onset of ENSO events (Rasmusson and Wallace, 1983, van Loon, private communication). It is possible that historical documents in South Africa could yield a long chronology of wet winters. It is interesting to note that the winter of 1652 (the year in which the Cape Colony was founded and a probable ENSO year in the present chronology) was notoriously cold and wet (Hutchins, 1889; Theal, 1907).

4. Conclusion

A survey of the literature concerning rainfall and flooding in Peru reveals that 1541, 1578, 1614, 1624, 1652, 1701, 1720, 1728, 1747, 1763, 1770, 1791, 1804, 1814, and 1828 are all probable years for the onset of major ENSO events. It is quite possible that other strong ENSO events during the period considered have escaped identification. Remarkably enough, some evidence for the extratropical teleconnections of these early ENSO events can be found in proxy data from Japan, Canada, and Iceland. However, the lack of clear signals in the proxy data in individual ENSO events suggests that it is probably unrealistic to expect to infer the chronology of the Southern Oscillation from extratropical data alone.

TABLE 5 The number of weeks during which drift ice was observed along the coast of Iceland in annual periods from October of one year through September of the next. Results for individual years are compared with 13-year running means. Data from Koch (1945) and Thorarinsson (1956).

Year	Weeks of Ice	13-Year Mean	Anomaly
1614–15	18	6.1	11.9
1624–25	17	7.4	9.6
1652–53	0	1.5	−1.5
1701–02	0	7.5	−7.5
1720–21	0	2.0	−2.0
1728–29	25	4.0	21.0
1747–48	0	9.8	−9.8
1763–64	10	4.9	5.1
1770–71	7	5.8	1.2
1791–92	24	10.5	13.5
1804–05	0	9.8	−9.8
1814–15	0	8.4	−8.4
1828–29	17	7.6	9.4
Mean anomaly			2.5
Standard deviation			9.3

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Appendix: Evidence for the occurrence of an ENSO event in 1532

As mentioned in Section 2, there has been some speculation that the march of the Spanish *conquistadores* from Tumbes to Cajamarca from May to November 1532 may have followed a rainy period during the earlier part of the year One possible route for this march does involve crossing about 200 km of the coastal desert. This is the path marked with dash-dot arrows in Fig. 1 (after Cohen, 1968), and appears to be consistent with the descriptions given in the well-known history of the conquest written by Prescott (1886). If this route were in fact taken, the task of moving the roughly 60 cavalrymen and 100 infantry would no doubt have been facilitated in a rainy "year of abundance" (although it is not clear that it would have been impossible in a normal year; e.g., Cohen, 1968, page 37). More relevant perhaps is the state of the rivers that the Spanish crossed. Prescott (1886) states that on, or shortly after 24 September, Pizarro and his men crossed the "smooth waters of the Piura." Unfortunately the precise source for this information is not cited by Prescott (although he did have access to relevant manuscript material). If Prescott's information is correct then it would indicate very unusual conditions since, as noted in Section 2, the Piura River is normally dry from July through December. It is possible, however, that Prescott has misinterpreted the story of a river crossing mentioned in the memoirs of Francisco de Jerez (who was a participant in the march and who acted as Pizarro's secretary) as referring to the Piura River. The relevant quote from Jerez reads "The governor (i.e., Pizarro) left the city of San Miguel in search of Atahualpa on 24 September 1532. On the first day of the journey he and his men crossed the river on two rafts, the horses swimming" (Cohen, 1968, page 75). Since San Miguel at this time was on the Chira River (somewhat north of the Piura; Eguigúren, 1894b), Raimondi (1876) interpreted this as a reference to a crossing of the Chira, which is a perennial stream. If this interpretation is correct, then there would not be any reference in the memoirs of Jerez to a crossing of the Piura River, and this would be consistent with normal conditions. There is, however, one further item in the work of Jerez that might be relevant to the dating of an ENSO year. Later in his narrative, he describes another river the Spaniards crossed after leaving the settlement of Motupe as follows. "Some days later he (Pizarro) crossed a tract of dry, sandy country to reach a well-populated valley through which ran a large and swift river, which was in spate" (Cohen, 1968, p. 81). Jerez does not give the name of this river but Raimondi (1876, p. 22) maintains that it must have been the Lambayeque, since "all other rivers in the region carry little water." The fact that the Lambayeque is a perennial stream means that the reference to its crossing is not a definitive indication of unusually wet conditions, although the remark about the flood stage does seem unusual for the time of year (presumably late October).

Schweigger (1959) has questioned the contention that the march of the conquistadores was aided by rain in the early part of 1532. Following Raimondi (1876), he suggests that Pizarro actually marched directly south from Tumbes through the Sierra de Amotape, where lack of water presumably was not a problem. This route follows the Inca highway through the mountains to the place where the original town of San Miguel was established (see Fig. 1). Schweigger also notes that no mention of unusual rains in 1532 is made by any of the early chroniclers of the conquest, although many of them comment on the remarkable dryness of the Peruvian coastal desert.

In summary, there is little direct evidence that 1532 was in fact a rainy year. Unless Prescott (1886) is correct in his identification of the Piura as one of the rivers that had to be crossed on rafts, all the accounts of river crossings appear to refer to perennial streams. There are several references in Jerez' memoirs to the dry, sandy conditions in the country between the river valleys.

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announcements[1]

Applications Sought for Senior and Postdoctoral Research Associateships

The National Research Council announces the 1987 Resident, Cooperative, and Postdoctoral Research Associateship Programs for research in the sciences and engineering to be conducted in behalf of 26 federal agencies or research institutions, whose laboratories are located throughout the United States. The programs provide Ph.D scientists and engineers of unusual promise and ability with opportunities to perform research on problems largely of their own choosing yet compatible with the research interests of the supporting laboratory. Initiated in 1954, the Associateship Programs have contributed to the career development of over 4000 scientists ranging from recent Ph.D. recipients to distinguished senior scientists

Approximately 450 new full-time associateships will be awarded on a competitive basis in 1987 for research in chemistry, earth and atmospheric sciences; engineering and applied sciences; biological, health, behavioral sciences and biotechnology, mathematics, space and planetary sciences; and physics Most of the programs are open to both United States and non-United States nationals and to both recent Ph.D. degree recipients and senior investigators.

Awards are made for one or two years; senior applicants who have held the doctorate at least five years may request shorter tenure. Stipends for the 1987 program year will begin at $26,350 a year for recent Ph.D.s and be appropriately higher for senior associates. A stipend supplement of approximately $5,000 may be available to regular (not senior) awardees holding recognized doctoral degrees in those disciplines wherein the number of degrees conferred by United States graduate schools is significantly below the current demand. In the 1986 program year these areas have been engineering, computer science, and space-related biomedical science

Reimbursement is provided for allowable relocation costs and for limited professional travel during tenure. The host laboratory provides the associate with programmatic assistance including facilities, support services, necessary equipment, and travel necessary for the conduct of the approved research program

Applications to the National Research Council must be postmarked no later than 15 January 1987 (15 December for NASA), 15 April and 15 August 1987. Initial awards will be announced in March and April (July and November for the two later competitions) followed by awards to alternates later.

Information on specific research opportunities and federal laboratories, as well as application materials, may be obtained from the Associateship Programs, Office of Scientific and Engineering Personnel, JH 608-D3, National Research Council, 2101 Constitution Avenue, N.W, Washington, DC 20418, (202) 334-2760.

Australian Weather Calendar Available

The 1987 issue of the Australian Weather Calendar is now available. The calendar, which features six color photographs and a variety of information on meteorological phenomena, is produced jointly by the Australian Bureau of Meteorology and the Australian Branch of the Royal Meteorological Society. Copies may be obtained from the Secretary of the Royal Meteorological Society (Australian Branch), P O Box 654E, Melbourne, Victoria, Australia 3001. The calendars are available for A$10, a price which includes airmail postage.

[1] Notice of registration deadlines for meetings, workshops, and seminars, deadlines for submittal of abstracts or papers to be presented at meetings, and deadlines for grants, proposals, awards, nominations, and fellowships must be received at least three months before deadline dates.—*News Ed.*

announcements (*continued on page 1403*)