TREE-RING AND GLACIAL EVIDENCE FOR THE MEDIEVAL WARM EPOCH AND THE LITTLE ICE AGE IN SOUTHERN SOUTH AMERICA

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Abstract. A tree-ring reconstruction of summer temperatures from northern Patagonia shows distinct episodes of higher and lower temperature during the last 1000 yr. The first cold interval was from A.D. 900 to 1070, which was followed by a warm period A.D. 1080 to 1250 (approximately coincident with the *Medieval Warm Epoch*). Afterwards a long, cold-moist interval followed from A.D. 1270 to 1660, peaking around 1340 and 1640 (contemporaneously with early *Little Ice Age* events in the Northern Hemisphere). In central Chile, winter rainfall variations were reconstructed using tree rings back to the year A.D. 1220. From A.D. 1220 to 1280, and from A.D. 1450 to 1550, rainfall was above the long-term mean. Droughts apparently occurred between A.D. 1280 and 1450, from 1570 to 1650, and from 1770 to 1820. In northern Patagonia, radiocarbon dates and tree-ring dates record two major glacial advances in the A.D. 1270–1380 and 1520–1670 intervals. In southern Patagonia, the initiation of the *Little Ice Age* appears to have been around A.D. 1300, and the culmination of glacial advances between the late 17th to the early 19th centuries.
Most of the reconstructed winter-dry periods in central Chile are synchronous with cold summers in northern Patagonia, resembling the present regional patterns associated with the El Niño-Southern Oscillation (ENSO). The years A.D. 1468–69 represent, in both temperature and precipitation reconstructions from tree-rings, the largest departures during the last 1000 yr. A very strong ENSO event was probably responsible for these extreme deviations. Tree-ring analysis also indicates that the association between a weaker southeastern Pacific subtropical anticyclone and the occurence of El Niño events has been stable over the last four centuries, although some anomalous cases are recognized.

1. Introduction

Paleoclimatic studies in the Southern Hemisphere have historically lagged those of the Northern Hemisphere. Recent Holocene records for the Southern Hemisphere, (particularly from South America), are comparatively rare. However, for a global interpretation of climate variations at any time scale, there is a need to examine and incorporate the records from the Southern Hemisphere.

In the Northern Hemisphere, the two most significant climatic events recognized during the last millennium are the *Medieval Optimum* and the *Little Ice Age*. The evidence for the *Medieval Optimum* period is mainly from Europe and the North Atlantic (Lamb, 1977; Williams and Wigley, 1983). A clear definition for the timing

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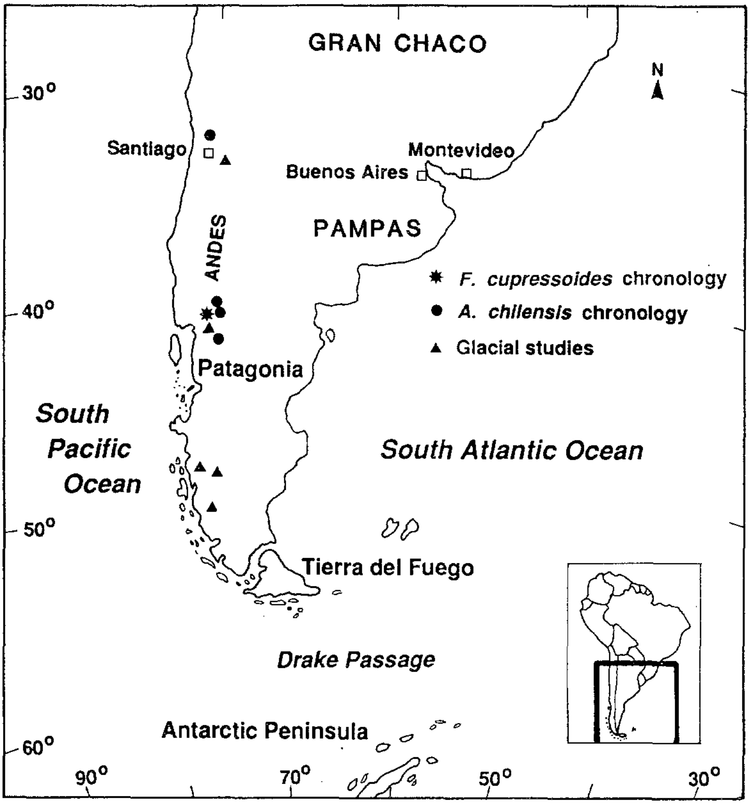

Fig. 1. Location map of tree-ring and glaciological records in southern South America.

and character of this period is not available on a global basis. Historical evidence of the *Little Ice Age* events is much more complete in Europe than elsewhere, but its expression in other continents is supported by much field evidence (Grove, 1988).

Southern South America (Figure 1), the only continental land mass in the Southern Hemisphere extending as far south as 55°S, presents a unique opportunity to reconstruct terrestrial records of paleoclimate in a region that is under the influence of polar and mid-latitude atmospheric circulation features (Taljard, 1972). This paper provides an overview of the most significant climatic fluctuations in southern South America during the last 1000 yr derived from tree-ring records and other paleoclimate indicators. Because no global consensus exits for the dates of the *Medieval Optimum* and the *Little Ice Age* events, Lamb (1977) dates, largely based on European evidences, are used here as temporal references only.

Climatic studies using modern instrumental records (i.e. over the past c. 100 yr) indicate that the South American climate is strongly affected by warm and cold events associated with the Southern Oscillation (SO) (Aceituno, 1988; Kiladis and Diaz, 1989). Consistent changes in the regional patterns of temperature and precipitation in South America associated with SO, provide the climatological

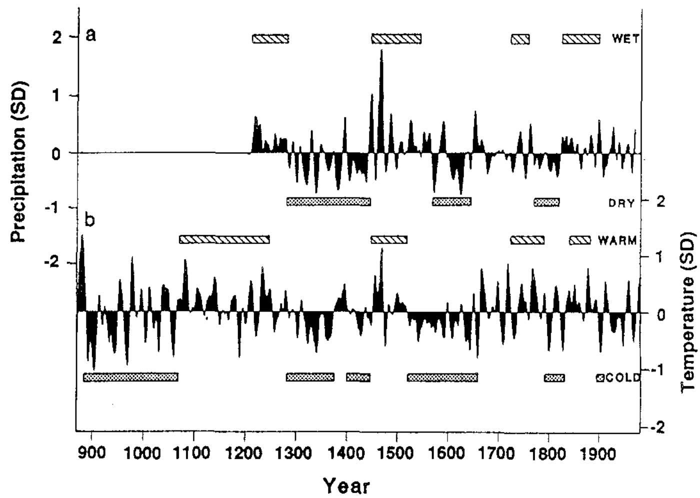

Fig. 2. Reconstructed climatic parameters derived from tree-ring records from southern South America. (a) Reconstruction of Santiago de Chile winter precipitation (Boninsegna, 1988); (b) Reconstruction of summer temperature in northern Patagonia (Villalba, 1990a). Tree-ring-based records are plotted in smoothed form to emphasize low-frequency variance (13 weight symmetrical low-pass filter; Fritts, 1976). Dashed/shaded bars indicate wet/dry and warm/cold intervals inferred from precipitation and temperature reconstructions, respectively.

basis for comparing paleoclimatological records from different regions in South America. An attempt to correlate different paleo-records in southern South America based on the modern patterns of the SO is presented. However, it is important to understand that the SO explains only part of the climate variability of southern South America. Although the current analysis focuses on the SO, other alternative sources of climatic variability could be related to the paleoclimate changes recorded.

2. Tree-Ring Record

Few tree-ring records in southern South America cover all of the last 1000 yr. Winter rainfall variations for Santiago, Chile (33°S) were reconstructed back to the year A.D. 1220 using a tree-ring chronology of *Austrocedrus chilensis*, from El Asiento, Aconcagua province, Chile (Boninsegna, 1988). The reconstruction accounts for 41% of the total variance over the calibration period. From A.D. 1220 to 1280, coinciding with the latter part of the *Medieval Optimum*, and from A.D. 1450 to 1550, rainfall was above the long-term mean (Figure 2). One long period of drought apparently occurred between A.D. 1280 and 1450, and two other drought periods appear from 1570 to 1650, and from 1770 to 1820. These winter rainfall variations are representative of precipitation variations in central Chile from 30 to 36°S. Dry winters are better reconstructed by the model than wet winters (Boninsegna, 1988).

Millennium-old *Fitzroya cupressoides* trees, located in the Río Alerce valley, Río Negro province, Argentina (41°S), were used to develop a 1120-yr reconstruction of summer temperatures (Villalba, 1990a; Figure 2). The variance in summer temperature explained by ring-width variations was slightly over 41%. The model estimates warm summers better than cold (Villalba, 1990a). The reconstruction of the summer temperature departure for northern Patagonia shows distinct episodes of higher and lower temperature during the last 1000 yr. The first cold interval was from A.D. 900 to 1070, which was followed by a warm period A.D. 1080 to 1250 (approximately coincident with the *Medieval Warm Epoch* of Europe; Lamb, 1977). Afterwards, a long, cold interval followed from A.D. 1270 to 1660, peaking around 1340 and 1640 (contemporaneously with *Little Ice Age* events in the Northern Hemisphere; Lamb, 1977). This cold interval was interrupted by a relatively short warm period between A.D. 1380 and 1520. Warmer conditions then resumed between A.D. 1720 and 1790. The mean temperature departure for the coldest interval (A.D. 1520 to 1660) is estimated to be 0.26°C lower than that for the warmest interval (A.D. 1080–1250). The temperature difference between these two intervals is significant at 99.99% level of significance (two-tailed test; Fritts, 1976). Considering that the model underestimates the real value of cold years, the temperature differences between these two intervals would be probably greater. Correlation between the Río Alerce reconstruction and a set of regional weather stations indicates that the tree-ring variations at this site are correlated with a homogeneous summer temperature pattern covering Patagonia east of the Andes from 38° to 50°S (Villalba, 1990a).

Comparison of the reconstruction of winter precipitation from central Chile with the summer temperature reconstruction from northern Patagonia, indicates that most of the winter-dry periods in central Chile are synchronous with cold summer temperatures in northern Patagonia (Figure 2). For example, during the periods A.D. 1280 to 1380 and 1570 to 1660, precipitation in central Chile was below the series mean, and northern Patagonia recorded the coolest summers of the last 1000 yr; conversely, from A.D. 1450 to 1520, from 1720 to 1760, and from 1850 to 1891, both rainfall in central Chile and Summer temperatures in North Patagonia were above the respective mean values. These climatic patterns resemble the present regional weather patterns associated with El Niño-Southern Oscillation events (Aceituno, 1988; Kiladis and Diaz, 1989).

3. Glacial Record

In central Chile, radiocarbon dates indicate advances of Los Cipreses Glacier (34°S) at the beginning of the fourteenth century and more recently around the 1860s (Röthlisberger, 1986). At a latitude of 41°S, radiocarbon dates of tree trunks overriden by the Río Manso Glacier indicate major glacial advances in A.D. 1040, 1330, 1365, 1640 and during the period A.D. 1800–1850 (Röthlisberger, 1986; Figure 3, and Table I). For the nearby Frías Glacier (41°10'S), two major glacial

TABLE I: Radiocarbon dates related to glacier advances in southern South America

No.	Date (years B.P.)	Location	Reference
1	Modern	Glaciar Los Cipreses, Chile (34° S)	Röthlisberger (1986)
2	625±155	Glaciar Los Cipreses, Chile (34° S)	Röthlisberger (1986)
3	Modern	Glaciar C. Overo, Argentina (41° S)	Röthlisberger (1986)
4	Modern	Ventisquero Negro, Argentina (41° S)	Röthlisberger (1986)
5	300±85	Ventisquero Negro, Argentina (41° S)	Röthlisberger (1986)
6	620±50	Ventisquero Negro, Argentina (41° S)	Röthlisberger (1986)
7	585±50	Ventisquero Negro, Argentina (41° S)	Röthlisberger (1986)
8	940±110	Ventisquero Negro, Argentina (41° S)	Röthlisberger (1986)
9	670±85	Glaciar Ofhidro, Chile (48° S)	Mercer (1970)
10	1180±175	Ventisquero O'Higgins, Chile (48° S)	Röthlisberger (1986)
11	165±50	Ventisquero Bravo, Chile (48° S)	Röthlisberger (1986)
12	270±100	Ventisquero Bravo, Chile (48° S)	Röthlisberger (1986)
13	665±80	Ventisquero Bravo, Chile (48° S)	Röthlisberger (1986)
14	240±50	Ventisquero Huemul, Chile (48° S)	Röthlisberger (1986)
15	310±80	Ventisquero Huemul, Chile (48° S)	Röthlisberger (1986)
16	425±45	Ventisquero Huemul, Chile (48° S)	Röthlisberger (1986)
17	465±65	Ventisquero Huemul, Chile (48° S)	Röthlisberger (1986)
18	470±55	Ventisquero Huemul, Chile (48° S)	Röthlisberger (1986)
19	895±85	Ventisquero Huemul, Chile (48° S)	Röthlisberger (1986)
20	205±50	Ventisquero Perro, Chile (51° S)	Röthlisberger (1986)
21	260±50	Ventisquero Perro, Chile (51° S)	Röthlisberger (1986)
22	295±75	Ventisquero Perro, Chile (51° S)	Röthlisberger (1986)
23	345±100	Ventisquero Perro, Chile (51° S)	Röthlisberger (1986)
24	795±80	Ventisquero Perro, Chile (51° S)	Röthlisberger (1986)
25	945±50	Ventisquero Torres, Chile (51° S)	Röthlisberger (1986)
26	235±65	Ventisquero Frances, Chile (51° S)	Röthlisberger (1986)
27	675±45	Ventisquero Frances, Chile (51° S)	Röthlisberger (1986)

advances are indicated for the A.D. 1270–1380 and 1520–1670 intervals (Villalba *et al.*,1990). However, only the latter advance has been adequately dated using tree-ring and historical records. In the South Patagonian icefield (48°S) the initial stages of Mercer's *Third Neoglacial* events are dated about A.D. 1300. In the same area, assuming a delay of c. 70 yr between deglaciation and tree establishment, the culmination of glacial advances has been estimated between the late 17th and the early 19th century (Mercer, 1968, 1970).

Most radiocarbon dates are centered around three periods: from A.D. 1280 to 1460, from 1560 to 1690, and around 1860. Radiocarbon dates 8, 19, and 25 in Table I, appear to be related to a glacier advance at the end of the 11th century. With the exception of radiocarbon date 24, no other dates suggest a glacier advance between A.D. 1100 and 1280 (Figure 3). Other intervals in which glacial recession

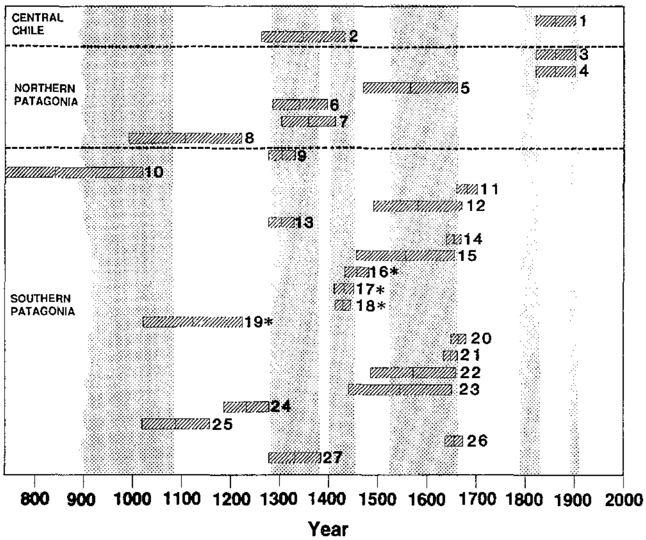

Fig. 3. A compilation of radiocarbon dates associated with glacier advances along the Andes ranges of southern South America during the last millennium. Radiocarbon dates are listed in Table I according to the number assigned in this Figure. Shaded intervals correspond to cool summer periods in northern Patagonia reconstructed from tree-rings (Villalba, 1990a). Radiocarbon dates have been calibrated following Stuiver and Becker (1986). Boxes represent radiocarbon dates (central line) with their respective standard deviations. An asterisk (*) indicates fossil tree-trunks not *in situ*.

probably occurred are: from A.D. 1440 to 1560, from 1700 to 1800, and from 1850 to 1900. Since the mid-19th century, a clear trend of glacier recession has occurred in most of the glaciers along the Andes (Clapperton, 1983; Rabassa and Clapperton, 1990).

When the glacial record is compared with the historical record of El Niño events (Quinn and Neal, 1992; stronger events: M+ to VS intensity levels), glacial advances and retreats appear to be associated with periods of low and high recurrence of El Niño events, respectively. Certainly, the most unusual changes in the El Niño event recurrence occur from the A.D. 1620–1680 period, with 7 events (none very strong), to the A.D. 1680–1740 period, with 13 events, 2 of which were very strong El Niño events. A similar change in the event frequency is also observed from the A.D. 1830–1860 period, with 3 events (none very strong), to the 1864–1891 period, with 8 events, two of which were very strong events. Quinn *et al.* (1987), and Quinn and Neal (1992) indicate that the latter change in El Niño event frequency may have been due to the general warming that followed the late phase of the *Little Ice Age*. The relationship between glacial advances and low frequency changes of El Niño events appears to be valid for most of the temperate glaciers in Patagonia (Villalba *et al.*, 1990), however, the response may be different in subtropical South America. In effect, in the dry Andes of Argentina and central Chile (30 to 35°S), glacial advances mainly respond to an increase in annual precipitation rather than a decrease in temperature (Leiva *et al.*, 1989). According to the modern patterns related to the Southern Oscillation, precipitation in central Chile is higher during the warm events, and therefore in this region glacial advances would have occurred during periods of high recurrence of El Niño events.

4. Southern South America and the Southern Oscillation

Heavy winter rainfall in central Chile is associated with positive anomalies during the developing stage of warm events of the Southern Oscillation (SO). Conversely, most cold events correspond to dry conditions (Rutllant and Fuenzalida, 1991). On the other hand, in northern Patagonia positive departures of summer temperature follow the warm events of the SO (Kiladis and Diaz, 1989). Warm and cold events of the SO (after Kiladis and Diaz, 1989) and El Niño events (from Quinn and Neal, 1992) were compared simultaneously with both the winter rainfall reconstruction in central Chile and the summer temperature reconstruction in northern Patagonia. Only the years of simultaneous positive and negative departures were tested. For the A.D. 1877–1972 interval, based on a total of 22 yr in which both series show simultaneously positive departures from the mean values, 17 years are related to warm events of the SO (Table II). A similar analysis between 1886 and 1972 indicates that from a total of 25 yr in which both series show negative departures from the mean, 18 cases can be associated with cold events of the SO. These relationships between tree-ring departures and the SO events are significant at the 95% level of significance (sign test; Fritts, 1976).

Based on the previous analysis, the occurence of a warm event of the Southern Oscillation in years in which both reconstructions show positive departures (above average winter rainfall in central Chile, and above average summer temperature in northern Patagonia) is highly probable. Conversely, negative departures in both series could indicate years of cold events. However, due to the autocorrelation in both temperature and precipitation reconstructions, it is impossible to establish if two or more consecutive departures of the same sign respond to a single, or more than one SO event. Therefore, the number of positive (negative) departures by decade is only a relative measure of the dominance of warm (cold) events than the actual frequency of warm (cold) events. Examination of both reconstructions shows the occurrence of a relatively high number of years with high rainfall in central Chile and warm summers in Patagonia in the following decades: A.D. 1240, 1460, 1520, 1740, and 1870 (Figure 4). On the other hand, the decades which record high number of years with simultaneous dry winters in central Chile and cold summers in northern Patagonia are A.D. 1360, 1470, and 1800 (Figure 4).

The years A.D. 1468–69 represent, in both reconstructions, the highest departures from their respective averages during the last 1000 yr. A warm event of the SO, larger in magnitude to those historically recorded, is probably responsible for these extreme deviations (Figure 5). Another important warm event may also be associated with higher departures in the years A.D. 1395–96. Coincidentally, corrected radiocarbon dates from detrital wood contained in flood sediments in the

TABLE II: Tree-ring reconstruction deviations and El Niño-Southern Oscillation (ENSO). Simultaneous positive and negative departures of winter rainfall in central Chile and summer temperature in northern Patagonia in relation to warm (dots) and cold (diamond) events of the El Niño-Southern Oscillation, respectively. Singles, and groups of 2 or 3 yr, associated with an ENSO event are indicated by boxes

Year	Sum. temp.	Win. prec.	ENSO	Year	Sum. temp.	Win. prec.	ENSO	Year	Sum. temp.	Win. prec.	ENSO
1877	+	+	•	1910	+	–		1943	+	–	•
1878	+	+	•	1911	+	–		1944	+	+	
1879	–	–		1912	+	+	•	1945	–	–	
1880	+	+	•	1913	+	–		1946	–	–	
1881	+	+		1914	+	+	•	1947	–	–	
1882	+	–		1915	–	–		1948	+	+	
1883	–	+		1916	–	–	◇	1949	–	–	◇
1884	–	+		1917	–	–		1950	–	+	
1885	–	+		1918	+	+	•	1951	+	–	
1886	–	–	◇	1919	+	+	•	1952	+	–	
1887	+	+	•	1920	–	+		1953	–	+	
1888	+	+	•	1921	–	+		1954	+	–	
1889	–	–	◇	1922	+	+		1955	–	+	
1890	–	+		1923	–	+		1956	+	+	
1891	+	+	•	1924	–	–	◇	1957	–	–	
1892	+	–		1925	–	+	•	1958	+	–	•
1893	+	–		1926	+	+	•	1959	+	+	
1894	+	–		1927	+	+		1960	+	–	
1895	–	–		1928	–	+		1961	+	+	
1896	+	–		1929	–	+		1962	0	+	
1897	+	–		1930	+	+	•	1963	–	+	
1898	–	+		1931	–	+	◇	1964	–	–	◇
1899	–	+		1932	–	–		1965	–	+	
1900	–	+		1933	–	–		1966	+	–	
1901	+	–		1934	–	–		1967	+	–	
1902	–	+		1935	+	–		1968	–	–	
1903	–	–	◇	1936	+	–		1969	–	–	
1904	–	+		1937	+	+		1970	–	+	
1905	–	+		1938	–	–	◇	1971	–	+	
1906	–	–	◇	1939	–	–		1972	+	+	•
1907	–	–		1940	–	+					
1908	–	–	◇	1941	–	+					
1909	–	–		1942	–	+					

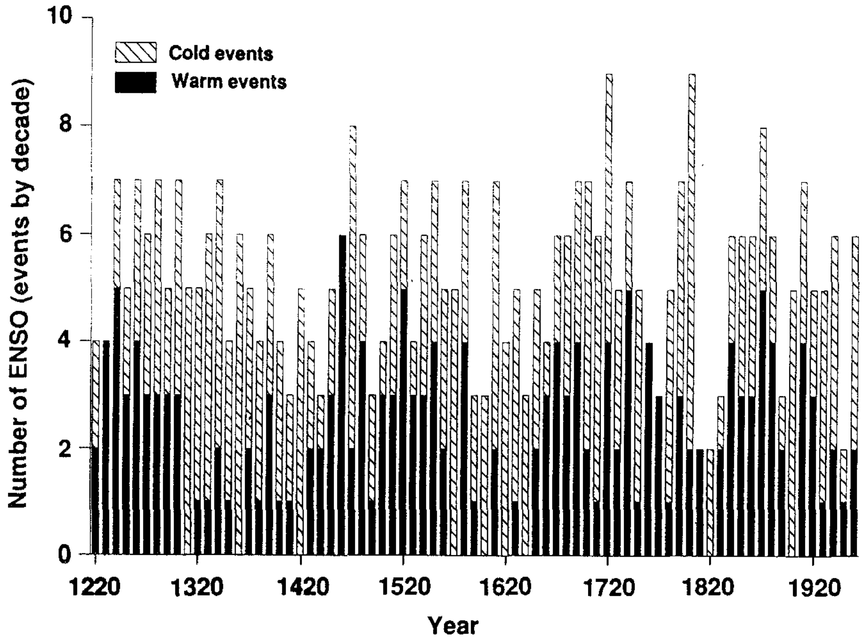

Fig. 4. Tree-ring reconstruction departures from the mean values and the El Niño-Southern Oscillation (ENSO) events. Number of years by decade with heavy winter rainfall (year 0) in central Chile concurrent with subsequent warm summers (year +1) in northern Patagonia (black bars), and low winter rainfall in central Chile concurrent with subsequent cool summer in northern Patagonia (dashed bars). Black and dashed bars are inferred to represent relative frequency of warm and cold ENSO events, respectively. See text for more details.

northern coast of Perú, also indicate the occurrence of strong El Niño events in A.D. 1460 ± 20, and A.D. 1380 ± 40 (Wells, 1987; event 11, Wells, 1990).

Heavy winter rainfall in central Chile occurs normally in El Niño years (Rutlland and Fuenzalida, 1991). They are both consequences of a weakeness in the southeastern Pacific subtropical anticyclone and remote forcing of extratropical systems by the anomalous tropical convection (Karoly, 1989). However, while high rainfall in the arid coastal lowlands of Perú results from the invasion of warm air masses from the north and west, precipitation in central Chile is related to a northward shift of the westerly storm tracks along the coast of Chile (Quinn and Neal, 1992; Aceituno, 1988).

A set of 17 tree-ring chronologies in Argentina and Chile were used to estimate the past position of the southeastern Pacific subtropical anticyclone (Villalba, 1990b). Eigenvector analysis of these chronologies revealed three dominant patterns of year-to-year tree-ring width variability. The third eigenvector, grouping the *Austrocedrus chilensis* chronologies between 39° and 42°S east of the Andes, is mainly related to the position of the anticyclone in summer. Eight of the ten most extreme northern positions, representing the weakest-index years of the southeast-

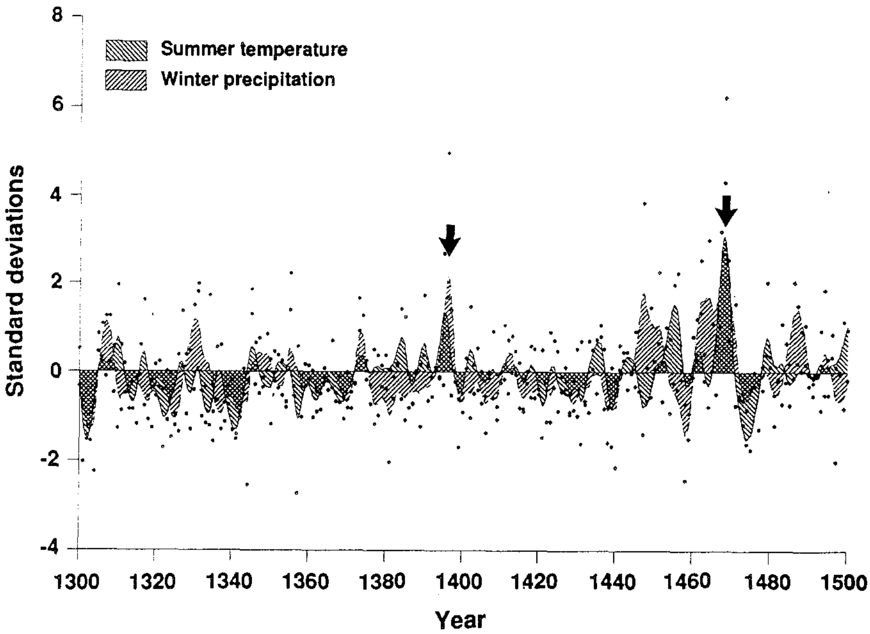

Fig. 5. Winter rainfall deviations in central Chile and summer temperature deviations in northern Patagonia for the interval A.D. 1300–1500. Note the extreme departures for the years 1395–96 and 1468–1469 (arrows). It is suggested that these departues are related to the occurrence of very strong El Niño events during those years. Actual precipitation and temperature departures are indicated by dots and diamonds, respectively.

ern Pacific anticyclone in summer, are associated with the El Niño events proposed by Quinn and Neal (1992). Two years (A.D. 1828 and 1926) are classified by these authors as very strong (VS) events, five years (A.D. 1589, 1600, 1652, 1940 and 1941) as strong (S or S+) events, and one year (1868) is indicated as a moderate (M+) event.

Winter rainfall variability in central Chile has been related to changes in the position and intensity of the adjacent subtropical anticyclone. An anticyclone displaced to the south is associated with relative dry conditions, while wet winters tend to occur when the anticyclone is shifted northward from its average latitudinal position (Rubin, 1955; Pittock, 1980; Minetti and Sierra, 1989). Consequently, the winter precipitation reconstruction of Santiago de Chile (Boninsegna, 1988) was adopted as representative of the winter anticyclone positions.

In general an association between a weaker southeastern Pacific anticyclone and the occurrence of the El Niño events is apparent (Table III). Comparison of the tree-ring estimates with the historical El Niño events (Quinn and Neal, 1992), shows that the Pacific anticyclone was displaced to the north (i.e. weaker subtropical pressure) in 67 and 75% of El Niño years for summer and winter seasons, respectively. Both relationships are significant at 99% level of significance (two-tailed test, Fritts,

TABLE III: The southeastern subtropical Pacific anticyclone and El Niño events. Comparison of the tree-ring estimated summer (a, Northern Patagonia) and winter (b, Central Chile) positions of the southeastern subtropical Pacific anticyclone with El Niño events (after Quinn and Neal, 1992). During El Niño years, the Pacific anticyclone was displaced to the north (i.e. weaker pressure) in 67 and 75% of the cases for summer and winter seasons, respectively. Years (shown in parenthesis) with anomalous anticyclone positions (in terms of the 'expected' behavior) are indicated by century and event strength. An asterisk indicates anomalous years (in terms of the 'expected' behavior), followed by normal years. If these years were considered as normal years (due to the autocorrelation in the tree ring estimates) the Pacific anticyclone would have been shifted north in 82 and 88% of El Niño years for summer and winter seasons, respectively. A.: Number of agreements by century. D.: Number of disagreements by centuries

Century		(a) Northern Patagonia El Niño events				Total number of	
		Very Strong	Strong plus	Strong	Moderate plus	Agree-ments	Disagree-ments
16th	A.	–	1	5	1	7	
	D.	1(1578)	–	–	2(1565*,1585*)		3
17th	A.	–	2	7	3	12	
	D.	–	1(1624)	3(1614,1660*, 1681)	1(1604)		5
18th	A.	2	–	4	4	10	
	D.	1(1791*)	2(1701,1747)	2(1736,1783*)	2(1718*,1778–9)		7
19th	A.	2	3	2	6	13	
	D.	1(1891*)	1(1871*)	1(1864)	4(1817,1819, 1832*,1897*)		7
20th	A.	1	–	5	4	10	
	D.	–	–	1(1917*)	3(1939*,1943, 1953*)		4
Total	A.	5	6	23	18	52(67%)	
	D.	3	4	7	12		26(33%)

Century		(b) Central Chile El Niño events				Total number of	
		Very Strong	Strong plus	Strong	Moderate plus	Agree-ments	Disagree-ments
16th	A.	–	1	7	4	12	
	D.	1(1578*)	–	–	1(1596)		2
17th	A.	–	2	7	2	11	
	D.	–	1(1624)	3(1671*,1681, 1692–3*)	2(1604*,1684)		6
18th	A.	2	2	4	5	13	
	D.	1(1791*)	–	2(1715–6,1736*)	1(1778–9)		4
19th	A.	2	4	3	6	15	
	D.	1(1828*)	–	–	4(1812,1817, 1819,1866*)		5
20th	A.	1	–	4	5	10	
	D.	–	–	2(1932,1957–8*)	2(1910,1943*)		4
Total	A.	5	9	25	22	61(75%)	
	D.	3	1	7	10		21(25%)

1976). This indicates the existence, during the last four centuries, of an atmospheric pattern similar to that observed today (Aceituno, 1988; Rutllant and Fuenzalida, 1991). However, some anomalies in terms of the 'expected' behavior need to be discussed. During the very strong A.D. 1578 El Niño event, both summer and winter estimates are far below the mean value, suggesting a regional southeastern Pacific anticyclone stronger than the normal. In particular, the year A.D. 1791, identified by Quinn and Neal (1992) as a very strong event (but just strong by Hocquenghem and Ortlieb, 1992), was not only climatically anomalous in central Chile but also in the Pampas of Argentina, where interannual rainfall variability is related to the El Niño-Southern Oscillation (Ropelewski and Halpert, 1987). According to Taulis (1934), precipitation in central Chile was below average (extremely dry) in 1791. In contrast to the modern patterns of the SO, Politis (1984) indicated that the year 1791 represented the most extreme dry episode during the 17th and 18th centuries in the Argentinean Pampas. Aceituno and Montecinos (1992) noted that the relationship between the SO and the interannual rainfall variability, and hence the strength of the southeastern Pacific anticyclone, has varied significantly in South America during the present century. These proxy records suggest that such variations in the relationship between ENSO and South American precipitation are part of the longer-term functioning of the ENSO system.

5. Discussion and Conclusions

In Patagonia, both tree-ring records and records of glacial variations indicate an interval of above average temperatures for A.D. 1080 to 1250. For this interval, the summer temperature reconstruction for northern Patagonia shows an increase in the frequency of warm years (without any obvious change in the intensity of warm years), and a decrease in the intensity of cold years. The whole interval is only interrupted by one cold period around A.D. 1190 (Figure 2). Interestingly, a similar cold event around A.D. 1190 has recently been reported for Tasmania, at the same latitude as northern Patagonia, by Cook *et al.* (1991). Below average temperatures occurred in the A.D. 1300 to 1380 and 1520 to 1660 intervals. During these cold summer periods in northern Patagonia, central Chile recorded the most intense droughts of the last 1000 yr.

In general, a tendency towards the simultaneous occurrence of positive (negative) departures of winter rainfall in central Chile and summer temperatures in northern Patagonia and warm (cold) events of the Southern Oscillation is apparent. Some departures from this general pattern could be explained. Positive departures both in central Chile precipitation and northern Patagonia summer temperatures occurred in 1948 (Table II). Even though this year is not listed in Quinn and Neal (1992) or in Kiladis and Diaz (1989) as a warm event, monthly sea surface temperatures at Puerto Chicama, Perú, exceed the mean annual cycle during the first half of 1948 by 1°C (Deser and Wallace, 1987). According to Rutlland and Fuenzalida

(1991), some dry winters in central Chile, not listed as cold events, showed anomalies distinctive of cold events. For example, during the dry 1968 winter in central Chile (followed also by a cold summer in northern Patagonia), the first half of the year presented negative departures in sea level pressure at Darwin and in the sea surface temperature at Puerto Chicama. Consequently, if this consideration is taken into account, the proposed relationships between simultaneous positive (negative) departures of rainfall and temperature in central Chile and northern Patagonia, respectively, and warm (cold) events of the SO appears highly consistent.

Kiladis and Diaz (1989), noted that during the year preceding the development of a warm event in the Southern Oscillation, climatic anomalies tend to be opposite to those during the following year. This biennial tendency of the Southern Oscillation is poorly reconstructed using *Fitzroya cupressoides* chronologies due to the high autocorrelation present in most of the tree-ring chronologies constructed for this species (Table II). Therefore, the total number of events (warm and cold) is a better indicator of extreme events in the Southern Oscillation than the frequency of warm or cold events considered separately. The periods A.D. 1240–1349, 1450–1489, 1510–1589, 1670–1759, 1780–1809, and 1840–1889, were intervals of high recurrence of the Southern Oscillation events (Figure 4). On the other hand, low event recurrence occurred from A.D. 1350 to 1449, from 1590 to 1669, and from 1810 to 1839. Most of these periods of high recurrence are also recognized by Quinn and Neal (1992).

During the 13th century (concurrent with the *Medieval Warm Period*), precipitation in central Chile and summer temperature in northern Patagonia were above average (Figure 2). If the same climatic anomalies observed today are responsible for the paleoclimatic changes reconstructed, warm-type events of the Southern Oscillation should have predominated over cold-type events during the *Medieval Warm Period*. For the Magdalena-Cauca-San Jorge river system, Van der Hammen (1991) recorded a period of low effective rainfall between 750 and 650 B.P. Low precipitation in northwestern South America is related to warm-type events of the Southern Oscillation (Aceituno, 1988). This suggests, in accordance with paleoclimate indicators from southern South America, an intensification of the warm-type events during the thirteenth century. Conversely, the prevalence of negative departures of winter rainfall and summer temperature from A.D. 1280 to 1380, and from A.D. 1520 to 1650, simultaneous with the *Little Ice Age*, could be related to a predominance of cold- over warm-type events of the SO.

As has been mentioned, the most significant patterns of climatic variations associated with the SO are relatively well known (Aceituno, 1988; Kiladis and Diaz, 1989; Rutlland and Fuenzalida, 1991). However, they only explain part of the total variance of the climate in southern South America. Other tropical and extratropical atmospheric-oceanic components of the climate system play an important role in climate changes in South America (COHMAP members, 1988). They could in part be responsible for the paleoclimate changes recorded in South America. Consequently, more reliable sets of paleodata for southern South America are needed in order to aid our understanding of past and present atmospheric changes, and to help us obtain a clearer regional climate chronology for the last 1000 yr.

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