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Winter-spring precipitation reconstructions from tree rings for northeast Mexico

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Abstract The understanding of historic hydroclimatic variability is basic for planning proper management of limited water resources in northeastern Mexico. The objective of this study was to develop a network of tree-ring chronologies to reconstruct hydroclimate variability in northeastern Mexico and to analyze the influence of large-scale circulation patterns, such as ENSO. Precipitation sensitive tree-ring chronologies of Douglas-fir were developed in mountain ranges of the Sierra Madre Oriental and used to produce winter-spring precipitation reconstructions for central and southern Nuevo Leon, and southeastern Coahuila. The seasonal winter-spring precipitation reconstructions are 342 years long (1659–2001) for Saltillo, Coahuila and 602 years long (1400–2002) for central and southern Nuevo Leon. Both reconstructions show droughts in the 1810s, 1870s, 1890s, 1910s, and 1970s, and wet periods in the 1770s, 1930s, 1960s, and 1980s. Prior to 1800s the reconstructions are less similar. The impact of ENSO in northeastern Mexico (as measured by the Tropical Rainfall Index) indicated long-term instability of the Pacific equatorial teleconnection. Atmospheric circulation systems coming from higher latitudes (cold

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fronts or ‘nortes’) and others developed in the Gulf of Mexico (tropical storms, hurricanes) also influence the climatic conditions characterizing this region. The recent development of new and longer tree-ring chronologies for the region will contribute to a better understanding of the interannual and multidecadal climatic variability of northeastern Mexico.

1 Introduction

The study of historical variability of atmospheric circulation patterns is basic to understand the current and future climatic changes and their effect on social and economic stability. The climate of northern Mexico is characterized by a seasonal precipitation regime and a strong monsoon component (Pyke 1972; Douglas et al. 1993; Higgins et al. 1999) with a pronounced maximum (>70%) of annual rainfall in the warm season (May–October), and less than 30% for the rest of the year (Mosiño and Garcia 1974). The precipitation in this region varies on time scales ranging from seasonal to decades and at the annual level has a total precipitation near 400 mm (Comisión Nacional del Agua 2002).

Water supply is a major constraint on the socioeconomic development of this region with a growing population currently over 6.5 million people, mostly located in state capital cities such as Monterrey, Nuevo Leon; Saltillo, Coahuila; and Victoria, Tamaulipas. To overcome the water limitation for agriculture, public, and industrial use, water is derived from reservoirs built along main streams and from groundwater drawn from aquifers at depths over 500 m. In this region, the present availability of water is 1,324 m^3 /$year^{-1}$/ per capita, which is rated as very low (Revenga et al. 2000), and will further decline with anticipated future declines due to increased demand from population, industry, and agriculture (Comisión Nacional del Agua 2005).

The lack of available data about long-term trends and variability of climate is a significant limitation to planning the appropriate and future use of these resources. Paleoclimatic studies can potentially provide data on the range and variability of precipitation for water resource planners. Therefore, the objective of this study is to use tree rings to develop precipitation reconstructions that can be used to examine the long-term hydroclimatic behavior over northeastern Mexico for the last several hundred years. These data would allow the detection of low frequency variability that could be beneficial for the proper management of the limited water resources in this region. Tropical SSTs can strongly influence winter-spring precipitation in northern Mexico, especially during warm ENSO events (Ropelewski and Halpert 1989; Stahle et al. 1998, Magaña et al. 1999). On the other hand, summer precipitation is affected by the North American monsoon system (Conde et al. 1997, Therrell et al. 2002). Agriculture, forage productivity, timber production and urban water supply are of critical importance for the economy of northern Mexico and are strongly influenced by variability in both winter and summer precipitation. In this study long-term winter-spring precipitation reconstructions for northeastern Mexico (part of Coahuila, and the states of Nuevo Leon and Tamaulipas) were developed using early wood chronologies of Douglas-fir (*Pseudotsuga Menziesii* Mirb. Franco) collected at several locations in the Sierra Madre Oriental (SMO). These reconstructions are analyzed and linked to large scale climatic forcing factors. The reconstructed dry and wet episodes are validated by comparison with historical documents (when available) which also illustrate some of the human responses to climatic extremes.

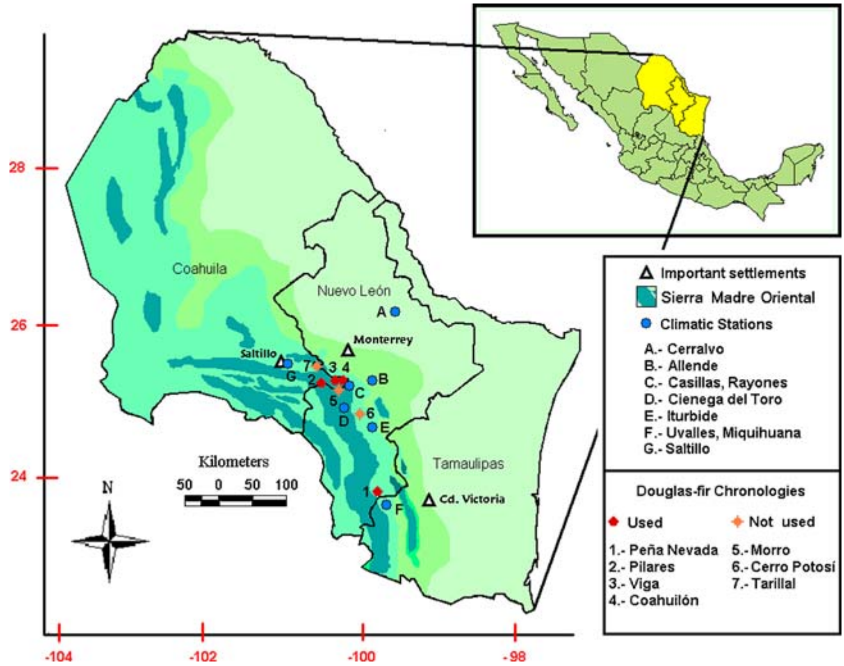

Fig. 1 Map of Douglas-fir chronologies for northeastern Mexico. The red dots represent the location of tree-ring chronologies in the states of Coahuila and Nuevo Leon

2 Methods

2.1 Study area

A network of tree-ring chronologies of Douglas-fir trees was developed from sites in the SMO. Five of the Douglas-fir chronologies (Viga, Coahuilon, Pilares, Morro, Tarillal) were located in montane or mixed conifer forests in a range known as Sierra de Arteaga, Coahuila within the SMO and near the city of Saltillo. An additional chronology was developed in Peña Nevada, Nuevo Leon, a range located 174 km south of the Sierra de Arteaga (Fig. 1).

Vegetation of montane forest ecosystems of the SMO is dominated by conifer species such as *Pinus culminicola*, *Abies vejarii*, *Pinus rudis*, *Pinus ayacahuite*, and *Pseudotsuga menziesii* (McDonald 1993). Climatic conditions at upper elevations (>2,800 m) are considered temperate and subhumid with a mean annual temperature of 13 °C (ranging from −3 to 18 °C) and annual precipitation between 450 to 550 mm distributed mainly in the summer months under the influence of the monsoon system, and from tropical storms and hurricanes that develop in the Gulf of Mexico (Instituto Nacional de Estadística, Geografía e Informática 1983; Magaña et al. 1999). Lower elevations are usually drier with an annual precipitation around 400 mm and mean temperatures in a range of 18 to 22 °C. The Sierra de Arteaga, Cerro la Peña and Cerro Potosi ranges are within the SMO on its northern limits and developed on Cretaceous sedimentary rocks dominated by limestone outcrops with karst depressions. Dominant soils are lithosols with less than 10 cm depth, although other soil classes are present as well. Soil depth increases at depressions and valley bottoms produced by alluvial deposition.

2.2 Tree-ring chronologies

Tree-ring chronologies were developed from increment cores and cross sections taken from Douglas-fir trees growing in mixed conifer stands along the SMO in the states of Coahuila and Nuevo Leon. The sampled trees were selected from relatively undisturbed stands in sites classified as low productivity (i.e., shallow and rocky soils and steep terrain) to maximize the climatic signal. Increment cores of 5 mm width were taken with a Swedish increment borer. The cores were mounted, sanded and crossdated using standard procedures (Stokes and Smiley 1968) and tree-ring series were measured with a VELMEX "TA" stage micrometer at 0.001 mm resolution. Crossdating and measurements were verified with COFECHA, (Holmes 1983; Grissino-Mayer 2001). New tree-ring chronologies of earlywood (EW), latewood (LW) and total ring width (RW) were developed for Douglas-fir stands.

Ring-width measurements were standardized with ARSTAN (Cook 1987). All series were first detrended either with a negative exponential curve or a straight line with a negative slope, and secondly with a spline with frequency response 0.5 at wavelengths N/2, where N is the length of the time series (Cook and Peters 1981).

Precipitation reconstructions were developed for Saltillo, Coahuila and central Nuevo Leon and then compared for similarities and common climate signal. The relationships between climate and tree-growth were investigated by correlation and response-function analysis (Fritts 1976). When possible, reconstructed drought periods were validated with historical documentation and compared to other climatic reconstructions available for northern Mexico (Diaz-Castro et al. 2002; Cleaveland et al. 2003; Gonzalez 2003; Villanueva et al. 2005).

To analyze the influence of atmospheric circulation patterns, the precipitation reconstructions were correlated with ENSO indices to indicate the strength of teleconnections from the equatorial Pacific to North America and regional hydroclimatic variability.

2.3 Climate records

Meteorological information was obtained from the climatic data base ERIC II (Instituto Mexicano de Tecnología del Agua 1977); the Mexican National Climatic Data Center's Global Historical Climatology Network (GHCN), and from individual meteorological stations made available through the Comisión Nacional del Agua (2002). The stations were selected on the basis of geographic coverage, correlation with tree growth, length of record, and data quality. Missing data were estimated by Paulhus and Kohler's method (1952), and double-mass analysis (Kohler 1949) was used to test homogeneity between stations (Table 1).

3 Results and discussion

3.1 Precipitation reconstructions

3.1.1 Climatic response of earlywood chronologies

Examination of correlations between monthly precipitation and the residual version of the EW chronologies for the Sierra de Arteaga, Coahuila showed statistically significant relationships for January through May although the results for February and May were only

Table 1 Location of climate stations and Douglas-fir earlywood chronologies from Coahuila and Nuevo Leon used in this study

Name	Lat °N	Long °W	Elevation (m)	Span (years)	Missing (%)			
Precipitation stations								
Saltillo	26.43	100.9	1,558	1941–2000	1.8			
Cerralvo	26.10	99.62	282	1957–1998	3.5			
Allende.	25.35	100.20	474	1961–1997	3.0			
Casillas, Rayones	25.22	100.22	183	1963–1998	3.7			
Cienega del Toro	25.08	100.33	700	1963–1997	4.0			
Iturbide	24.73	99.92	1,789	1948–1997	1.0			
Uvalles, Miquihuan	23.68	99.72	1,565	1961–1198	4.0			
Tree-ring chronologies								
Name	Lat °N	Long °W	Elevation (m)	Span (years)	No. trees/radii	MS[a]	SSS > 0.85[b]	Avg r
Viga	25.24	102.37	3,400	1659–2001	43/68	0.36	1827/4	0.59[c]
Coahuilón	25.23	100.33	3,200	1700–2001	44/74	0.35	1757/3	0.70[d]
Pilares	25.28	100.50	3,150	1775–2000	16/39	0.30	1784/4	0.56[e]
Tarillal	25.44	100.55	3,200	1872–2000	19/34	0.50	1887/3	0.61[f]
Morro	25.37	100.36	3,500	1771–2000	20/33	0.22	1873/4	0.51[g]
Peña Nevada	26.82	99.85	3,200	1396–2002	24/28	0.26	1650/5	0.48[h]
Cerro Potosí	24.83	100.07	2,500	1845–1995	14/29	—-	—-	—-

[a]Mean sensitivity is the average percentage change in chronology indices between years (Fritts 1976).
[b]Year where Subsample Signal Strength greater than 0.85 is attained (SSS > 0.85) and number of trees required. Average correlation between trees for common periods: [c]1940–2001, [d]1880–1997, [e]1881–2000, [f]1940–1998, [g]1910–1994, [h]1779–1951.

barely significant. The best seasonal correlation was obtained for the period January–June, which means that earlywood growth depends primarily on winter–spring precipitation. This precipitation is normally of low rainfall intensity that usually does not surpass basic infiltration, allowing water to be stored in the first soil horizons and used for tree growth during the later growing season. A similar climatic response for the earlywood growth was observed for the Douglas-fir from the Peña Nevada site, although the significant response in this case covered a shorter period extending from the previous December to the current April.

3.1.2 Reconstructed winter-spring precipitation for saltillo, coahuila

A seasonal winter–spring (January–June) precipitation reconstruction was developed for Saltillo, Coahuila. In producing this reconstruction, five earlywood chronologies of Douglas-fir developed from mixed-conifer stands at La Viga, El Coahuilon, Los Pilares, El Tarillal, and El Morro in the Sierra de Artega, Coahuila. Principal Component Analysis (PCA) indicated that the first principal component (PC1) explained 73% of the variance but that the Viga, Pilares, and El Coahuilon chronologies loaded with values of 0.91, 0.88, and 0.84,

Table 2 Verification statistics for the tree-ring reconstruction of Saltillo winter-spring precipitation (January–June) from an average of three earlywood Douglas-fir chronologies (El Coahuilon, La Viga and Los Pilares). The verification procedure uses the climate estimates derived in the calibration period

Period	Pearson Corr. (r)	Negative first difference[a]	Paired t-test of mean[b]	Sign test[c] (hit/miss)	Reduction of Error[d] (RE)
1976–2000	0.87*	3*	3.1*	25/6*	0.76*
1953–1975	0.63*	6*	1.86*	23/4*	0.33*

*Significant, $p < 0.05$.
[a]Observed and reconstructed data first differences ($t - t_{-1}$); the transformation removes trends that may affect the Pearson correlation coefficient. The sign of the first differences measures the association at high frequencies between observed and predicted values. The number of positive signs (agreement) expected by chance follows a binomial distribution and is $1/2n$, where n is the total number of observations. The test is significant whenever the number of signs exceeds the number expected from random numbers (Fritts 1991).
[b]Paired t-test value between observed and reconstructed means (Ott 1988).
[c]Signs of departures from the mean of each series (Fritts 1976). Means are subtracted from each series and the residuals are multiplied. A positive product is a "hit", if either observed or reconstructed data lie near the mean, the year is omitted from the test.
[d]Any positive result indicates that the reconstruction contributes unique paleoclimatic information (Fritts 1976).

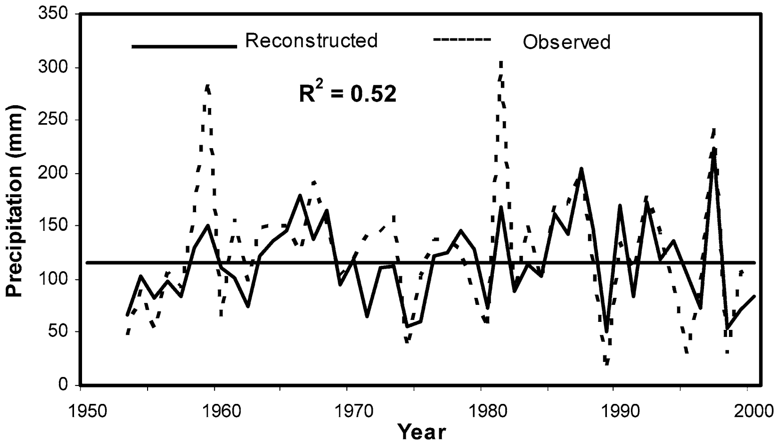

Fig. 2 Time series comparison of observed and reconstructed winter-spring (January–June) precipitation for the period 1953–2000. This period was divided in half for two separate sets of calibration and validation, 1976–2000 and 1953–1975, before calibrating on the full 48 years period

respectively. The average of these three chronologies was more highly correlated with the January–June precipitation totals at the Saltillo meteorological station than the PC1 factor scores. Therefore, we used these three chronologies for the reconstruction. Regressing the EW width on winter–spring precipitation calibrated 74% and 40% climatic variance in the 1976–2000, 1935–1975 subperiods and 52% over the 1953–2000 period (Fig. 2). The regression coefficients were not statistically different between the two subperiods and residuals from the regressions were statistically random indicating an appropriate model for reconstruction purposes. The calibration-verification procedure indicated that the reconstruction models pass the statistical test of accuracy when compared to independent climatic data (Table 2). Therefore, we used the total period of available climatic data to derive a bivariate linear model for the reconstruction. This 1659–2001 reconstruction is 123 years longer than

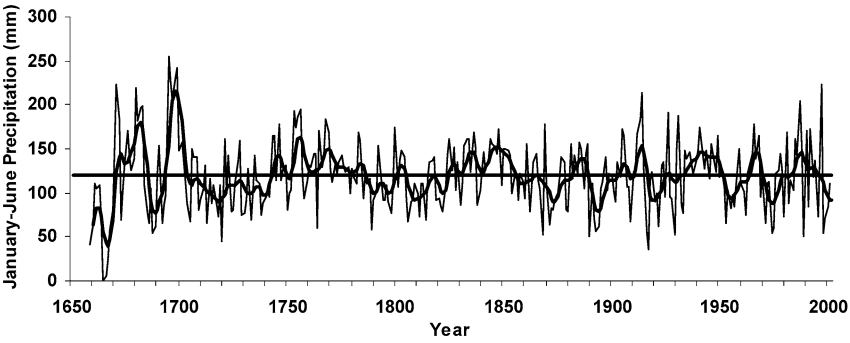

Fig. 3 Seasonal winter-spring (January–June) precipitation reconstruction series for the period 1659–2000 at Saltillo, Coahuila. The mean of the reconstruction is 120.0 mm with a standard deviation of 39.6 mm. A decadal smoothing spline has been fitted to the reconstruction to emphasize long-term droughts. Some of the worst droughts in the reconstruction were recorded in the 1660s, 1680s, 1710s, 1800s, 1870s, 1890s, 1910s, 1950s, and 1970s

a previous precipitation reconstruction for this mountain range based exclusively on a single chronology (Pohl et al. 2003). The reconstruction shows high interannual and interdecadal variability that characterizes winter-spring precipitation on this region (Fig. 3).

In common with previously developed precipitation reconstructions for northern Mexico (Villanueva and McPherson 1999; Diaz-Castro et al. 2002; Therrell et al. 2002; Cleaveland et al. 2003; González-Elizondo et al. 2005; Villanueva et al. 2005; Villanueva et al., in press), droughts were common during the 20th century, especially in the 1950s and 1960s. In the 19th century some this reconstruction shows severe droughts in the 1810s, 1870s, and 1890s. Additional droughts were detected for the period 1660s, 1690s, and 1710s (Table 3). Many of this droughts produced agricultural crisis and limited food availability, especially at the end of the 18th and 19th centuries (Cuellar 1979; Florescano 1980; García 1997). The reconstruction shows wetter pluvial episodes in the 1670s, 1690s, 1750s, 1840s, 1830s, 1910s, and 1940s. One of the most extended humid periods took place from 1833 to 1853, and is also seen in the adjacent American West (Fye et al. 2003).

The economic and social effects of droughts in this region are increasing in intensity, spatial extent, and duration due in part to the higher water demand for industrial, agricultural, and other human uses (Allanach and Johnson-Richards 1995). The establishment of settlements in places prone to droughts is exacerbates the impacts of natural climate variability on this activities in this region and many other parts of Mexico (Magaña et al. 1999).

3.1.3 Reconstructed winter-spring precipitation for central and southern nuevo leon

One of the longest precipitation reconstructions for northeastern Mexico was developed from a Douglas-fir earlywood chronology. This 602-year long chronology (1400–2002) was significantly correlated with the seasonal winter–spring (December–April) precipitation between 1964 and 1967 from a grid of climatic stations located in central and southern Nuevo Leon (Fig. 1).

The calibration and verification procedures were statistically significant. Regressing the EW width on winter-spring precipitation succeeded in calibrating 52% and 51% climatic variance in 1981–1997 and 1964–1980 subperiods and 43% over the full period (Fig. 4). The regression coefficients were not statistically different between the two subperiods and

Table 3 Dry and wet periods for the Saltillo and Nuevo Leon precipitation reconstructions based on a standard deviation below an above the mean, respectively

Saltillo							
Dry events				Wet events			
Period	Mean Ppt (mm)	Duration (years)	Rank	Period	Mean Ppt (mm)	Duration (years)	Rank
1659–1670	71.1	12	1	1671–1684	151.1	14	2
1685–1692	91.8	8	2	1693–1702	178.0	10	1
1712–1720[a]	95.3	9	6	1752–1758	149.0	7	3
1806–1813[a]	95.7	8	8	1766–1770[b]	145.9	5	5
1870–1875[a]	95.2	6	5	1833–1836	144.5	4	6
1889–1897	94.4	9	3	1842–1853	144.1	12	8
1917–1922[a]	95.6	6	7	1911–1914	147.2	4	4
1953–1956	95.2	4	4	1939–1945[b]	143.4	7	9
1970–1976[a]	96.0	7	10	1965–1967[b]	144.5	3	7
1998–2001	95.9	4	9	1986–1988[b]	143.4	3	10
Nuevo Leon							
Dry events				Wet events			
1402–1404	207.3	3	9	1422–1437	285.8	16	9
1412–1420	204.6	9	3	1461–1471	314.5	11	2
1439–1459	180.5	21	1	1480–1484	284.1	5	14
1498–1502	207.8	5	11	1498–1493	285.5	5	10
1516–1537	208.1	22	14	1505–1514	325.0	10	1
1578–1589	208.0	12	13	1546–1554	297.6	9	5
1629–1632	206.1	4	5	1616–1621	284.4	6	11
1694–1701	208.9	8	17	1642–1652	291.3	11	6
1715–1724[a]	202.1	10	2	1659–1661	283.8	3	16
1784–1789	206.7	6	6	1688–1690	284.2	3	12
1806–1809[a]	209.2	4	18	1726–1738	300.3	13	3
1817–1820	207.1	4	8	1768–1779[b]	284.1	12	13
1867–1875[a]	207.0	9	7	1895–1905	300.0	11	4
1907–1910	207.5	4	10	1938–1939[b]	283.9	2	15
1916–1917[a]	207.9	2	12	1965–1966[b]	287.6	2	8
1927–1933	208.9	7	16	1987–1994[b]	288.4	6	7
1969–1972[a]	206.4	4	4				
1979–1985	208.7	7	15				

[a]Dry and [b]wet events common to the precipitation reconstructions.

residuals from the regressions were statistically random indicating an appropriate model for reconstruction purposes. The calibration-verification procedure indicated that the reconstruction models pass the statistical test of accuracy when compared to independent climatic data (Table 4). Therefore, the total period of available climatic data (1964–1997) were used to derive the bivariate linear regression model for reconstruction purposes.

The seasonal precipitation reconstruction (December–April) extends from 1402 to 2002 (602 years) showing recurrent droughts affecting this region (Fig. 5). The most significant drought episodes in the 20th century occurred in the 1907–1910 and 1969–1972 periods. Analogous droughts were reconstructed for the periods 1439–1459, 1516–1537, 1629–1632,

Table 4 Calibration-verification statistics for the winter-spring (December–April) precipitation reconstruction of central and southern Nuevo Leon. The verification procedure uses the climate estimates derived in the calibration period

Period	Pearson Corr. (r)	Negative First difference[a]	Paired t-test of mean[b]	Sign test[c] (hit/miss)	Reduction of Error[d] (RE)
1981–1997	0.72*	2*	2.1*	14/3*	0.52*
1964–1980	0.52*	7NS	2.7*	10/7NS	0.32*

*Significant, $p < 0.05$.
[a]Observed and reconstructed data first differences ($t - t_{-1}$); the transformation removes trends that may affect the Pearson correlation coefficient. The sign of the first differences measures the association at high frequencies between observed and predicted values. The number of positive signs (agreement) expected by chance follows a binomial distribution and is $1/2n$, where n is the total number of observations. The test is significant whenever the number of signs exceeds the number expected from random numbers (Fritts 1991).
[b]Paired comparison of observed and reconstructed data means (Ott 1988).
[c]Signs of departures from the mean of each series (Fritts 1976). Means are subtracted from each series and the residuals are multiplied. A positive product is a "hit". If either observed or reconstructed data lie near the mean, the year is omitted from the test.
[d]Any positive result indicates that the reconstruction contributes unique paleoclimatic information (Fritts 1976).

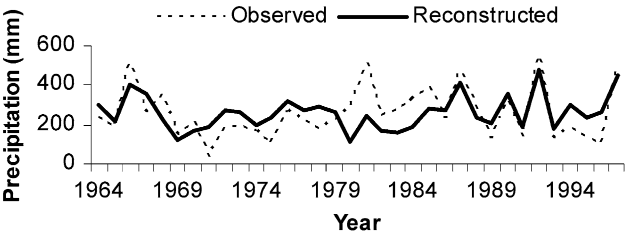

Fig. 4 Time series comparison of observed and reconstructed seasonal winter-spring precipitation (December–April) for the period 1964 to 1997. This period was divided in half for two separate sets of calibration and validation, 1981–1997 and 1964–1980, before calibrating on the full 34 year period

1694–1701, 1784–1789, 1806–1809, 1817–1820, and 1867–1875 (Table 3). Some of the droughts observed in this reconstruction have also been documented for the Valley of Mexico (Florescano 1980), especially those in the 1860s and 1960s when climatic anomalies may have expanded from central to northern Mexico as suggested by other precipitation reconstructions (Therrell et al. 2002; Cleaveland et al. 2003, Pohl et al. 2003; Villanueva et al. 2005). Wetter episodes were observed in the 1420s, 1460s, 1500s, 1540s, 1610s, 1640s, 1730s, 1770s, 1890s, 1930s, and after 1980 (Table 3). Some of these pluvial events are common to precipitations reconstructions elsewhere in northern Mexico and the United States (Cleaveland et al. 2003; Fye et al. 2003).

The lack of historical information for northeastern Mexico prior to the 16th century prevents independent verification of the reconstruction; however, severe droughts affecting other regions of Mexico and the United States of America at some of these times, e.g. the drought of the 1450s and 1460s in the Valley of Mexico produced shortage of food and drinking water for the Aztec civilization (Garcia 1993; Garcia et al. 2003). A century later a megadrought in the 1560s of greater magnitude and duration may have magnified the presence of infectious diseases that depleted indigenous populations in that region (Acuna-Soto et al. 2002; Therrell et al. 2004, 2005). The 1580s drought appears to have encompassed areas of

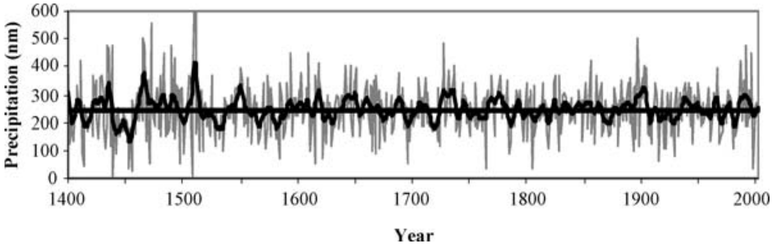

Fig. 5 Seasonal winter-spring (December–April) precipitation reconstruction series for the period 1400–2002 in central and southern Nuevo Leon region. The mean of the reconstruction is 246 mm with a standard deviation of 90.4 mm. A decadal smoothing spline has been fitted to the reconstruction to emphasize long-term droughts. Some of the worst droughts in the reconstruction were recorded in the 1410s, 1450s, 1500s, 1570s, 1630s, 1790s, 1810s, 1870s, 1910s, 1960s, and 1980s

northern Mexico and extended across much of the continental United States (Stahle et al. 2000). The atmospheric mechanisms responsible for this climatic anomaly have yet to be investigated in detail and may involve the influence of the equatorial Pacific conditions during that time period.

3.2 Enso teleconnection to the northeastern precipitation reconstructions

Cool season precipitation in northern Mexico and the southwestern United States is strongly linked with the Southern Oscillation (Ropelewski and Harper 1989; Stahle et al. 1998; Magaña et al. 1999; Cleaveland et al. 2003). This relationship is clearly recorded in the tree rings of Douglas-fir growing in the Sierra Madre Occidental of Durango, Chihuahua, and Sonora (Stahle and Cleaveland 1993), but has not been investigated for the Sierra Madre Oriental in northeastern Mexico.

The ENSO extra-tropical teleconnection to northern Mexico is quite strong, but the strength and spatial extent varies over time (Stahle et al. 1998; Cleaveland et al. 2003). This lack of stability is illustrated by the variability of correlation with the Tropical Rainfall Index (TRI) an estimate of the ENSO variability using rainfall anomalies in the central Pacific (Wright 1979). Comparing the TRI and Saltillo reconstruction for successive 20-year subperiods during the 1896 to 1895 period shows high variability ranging from 0.25 (1935–1954) to 0.64 (1895–1914) (Fig. 6). The correlations were not significant for the 1894–1914, 1915–1934, and 1975–1996 subperiods. A test of non-zero correlations for the extreme “r” values (0.64, 0.25) indicated that the difference was not statistically significant (Snedecor and Cochran 1989), which may mean that changes in the ENSO teleconnection detected elsewhere in northern Mexico and southwestern United States have not been of great influence on determining the precipitation variability observed on this region. The influence of cold fronts systems from higher latitudes, tropical storms, and hurricanes developed in the Gulf of Mexico may have a greater impact on the hydroclimatic variability that characterizes the northeastern region of Mexico.

Non-significant ($p > 0.05$) correlation values were found between the TRI and the Nuevo Leon precipitation reconstruction. The highest ($r = 0.28$) and lowest ($r = -0.10$) correlation values were found for the subperiods 1895–1914 and 1935–1954, respectively (Fig. 7). The lack of significant correlation between the TRI and reconstructed precipitation for this particular area could be attributed to the greater influence of other atmospheric phenomena that play a major role in influencing the amount of precipitation occurring in the cool season

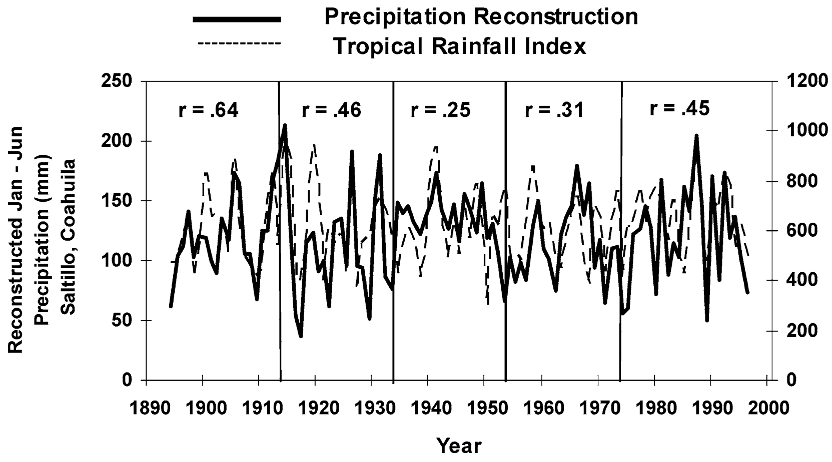

Fig. 6 Correlation (r) of the winter-spring (January–June) Tropical Rainfall Index with reconstructed Saltillo January–June precipitation in 20-year periods, an indication of the long-term instability of the Pacific equatorial teleconnection with northeastern Mexico climate. Statistical significance of correlation in periods 1894–1914 ($p < 0.001$), 1915–34 ($p < 0.04$), 1935–54 ($p = 0.29$), 1955–74 ($p = 0.18$), and 1975–96 ($p < 0.03$)

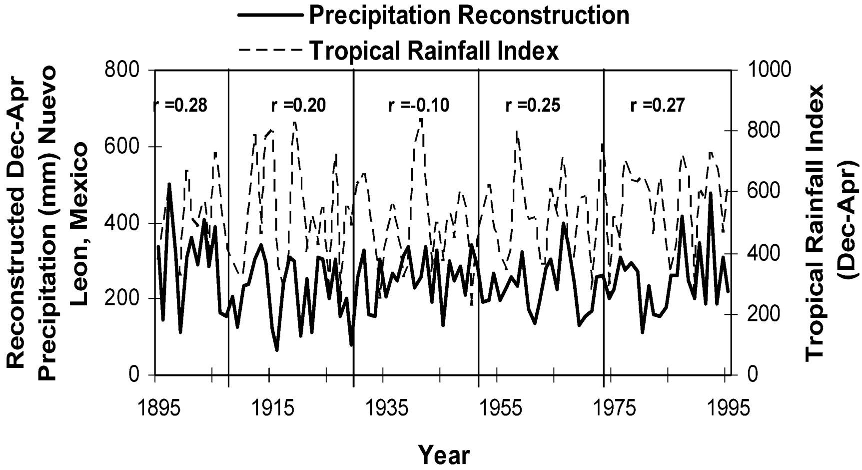

Fig. 7 Correlation (r) of the winter-spring (December–April) Tropical Rainfall Index with reconstructed Nuevo Leon December–April precipitation in 20-year periods, an indication of the long-term instability of the Pacific equatorial teleconnection with northeastern Mexico climate. Correlations changed for the different periods but none were significant ($p > 0.05$), indicating less influence of the ENSO teleconnection in this part of northeastern Mexico

for the central-southern Nuevo Leon region and parts of eastern Tamaulipas. Winter storms coming from higher latitudes along with the influence of climatic conditions developed in the Gulf of Mexico may explain predominant climatic conditions in this area (Magaña et al. 1999).

Table 5 Correlation values for 50-year subperiods and for the common period (1659–2001) between precipitation reconstructions for Saltillo, Coahuila and Nuevo Leon

Period	Length (years)	Correlation (r)	Probability (P)[a]
1659–1699	41	−0.29	0.06
1700–1749	50	0.536	0.0001
1750–1799	50	0.477	0.0005
1800–1849	50	0.446	0.001
1850–1899	50	0.536	0.0001
1900–1949	50	0.586	0.0001
1950–1999	50	0.745	0.0001
1659–2001	342	0.357	0.0001

[a]Correlation values were statistically significant except for the subperiod 1659–1699 ($p > 0.05$).

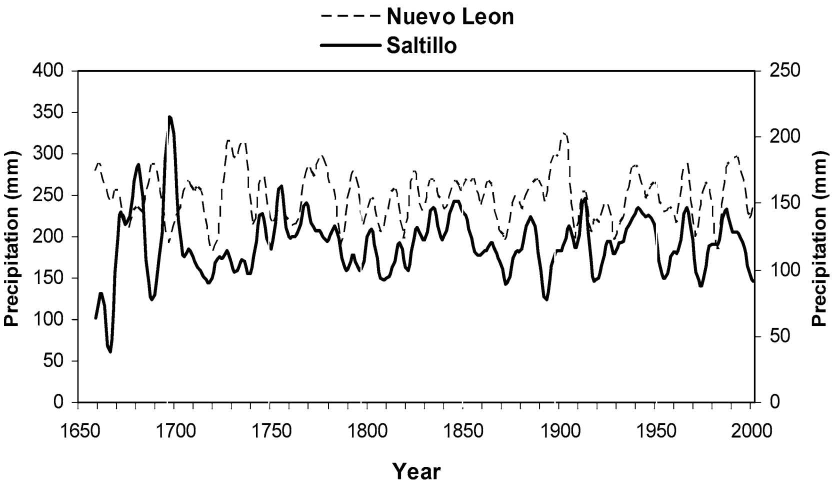

Fig. 8 Comparison of the decadally smoothed splines for the Saltillo and Nuevo Leon precipitation reconstructions. A very low correlation (r = 0.02, $p > 0.05$) was obtained when the smoothed cubic splines were compared for their common time period (1659–2001). However, significant correlations ($p < 0.05$) were obtained when the comparisons were done in 50-year subperiods, especially after 1800, when the reconstructions are detecting similar low frequency events

3.3 Climatic analysis of the precipitation reconstructions

The Saltillo and Nuevo Leon seasonal precipitation reconstructions showed a significant correlation response for the common time period (1659–2001; r = 0.36, $p < 0.0001$). The strength of the correlation was variable but generally increased after 1700 (Table 5). The low correlation observed before 1700 is probably affected by differences in sample size among the selected tree-ring chronologies. Sample depth dropped to three radii for the composite La Viga, El Coahuilon, and Los Pilares chronologies and to eight radii for the Peña Nevada chronology. Lower correlations were observed when comparing the decadal smoothed spline in the common period, although correlation increased after 1800 (Fig. 8).

This finding indicates that the hydroclimate variability in northeastern Mexico is probably being influenced by different circulation patterns, or alternately, similar atmospheric phenomena, but which may be modulated by different physiographic conditions.

Despite the hydroclimatic variability expressed in these reconstructions, several dry or wet periods shown here are known to have also affected extensive areas in Mexico and the continental United States. Droughts in the 1810s, 1860s, 1870s, and 1960s present in these reconstructions are also reflected in dryness for central and northern Mexico. Some of these droughts produced shortages of food, extensive fires, and epidemic outbreaks and possible were contributory factors in triggering some important events in the history of Mexico such as the Independence War (1810) and the Mexican Revolution (1910; Escobar 1997). The presence of these widespread events indicates that large scale atmospheric circulation patterns influence the climatic behavior over much of Mexico. There are now sufficient high-resolution tree-ring records that could be used to place the climatological context within a historical perspective.

4 Conclusions

These cool season (winter-spring) precipitation reconstructions developed for the northeastern Mexico region increases the availability of paleoclimatic information and contributes to a better understanding of the historical hydroclimatic variability and the influence of changes in atmospheric circulation patterns. These reconstructions indicate the presence of droughts of greater intensity and extent than those witnessed during the 20th century. They also show variations in the strength of correlations with the Tropical Rainfall Index indicating the necessity to explore in greater detail the ENSO circulatory pattern and the influence of cold fronts, tropical storms and other atmospheric phenomena in the Gulf of Mexico and that influence the climate variability in this region.

The network of tree-ring chronologies now available for several sites in Mexico will play an important future role in providing a better understanding of the past and potential future climate and the impact of atmospheric circulatory patterns on water availability. Additional climatic sensitive baldcypress (*Taxodium mucronatum*) and pinyon pine (*Pinus cembroides*) chronologies have recently been developed for the states of Nuevo Leon, Coahuila and Tamaulipas. These chronologies, together with a rich source of historical climate data, may provide the potential to document temporal and spatial patterns of past climate, as well as causal mechanisms and the impacts of extreme climatic events.

The lack of suitable proxy climatic records has in the past limited hydroclimatic analysis for water management and climate forecasting purposes. The new network of tree-ring chronologies will provide new proxy climatic records that, when linked to historical socioeconomic data will help to establish the full range of natural variability in precipitation and establish relationships between precipitation and large scale atmospheric circulation patterns that may contribute to better management of the limited water resources in northeastern Mexico.

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