HISTORICAL DROUGHTS IN NORTH-CENTRAL MEXICO

José Villanueva D*., Julián Cerano P[1]., Dave W. Stahle[2], Brian H. Luckman[3], Matthew D. Therrell[2]

[1]INIFAP CENID-RASPA, Gómez Palacio, Dgo.; [2]Department of Geosciences, University of Arkansas, Fayetteville, AR.; Department of Geography, University of Western Ontario, London, Ontario

1. INTRODUCTION

The study of historical variability of climate is basic to understand the current and future climatic changes and their effect on social and economic stability. The climate of northern and central 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). Water supply is a major constraint on the socioeconomic development of this region. 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 from tree rings 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 northern and central 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 and central Mexico and are strongly influenced by variability in both winter and summer precipitation. In this study long-term winter-spring precipitation reconstructions for northern and central Mexico were developed using early wood chronologies of Douglas-fir (*Pseudotsuga Menziesii* Mirb. Franco) and total ring width of Montezuma baldcypress (*Taxodium mucronatum* Ten.) collected at several locations in the Sierra Madre Oriental (SMO), Sierra Madre Occidental, and riparian areas in central and northern Mexico. 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.

* Corresponding author address: José Villanueva Díaz, INIFAP CENID-RASPA, Km 6.5 Margen Derecho del Canal Sacramento. Gómez Palacio, Durango. 35140. E-mail: Villanueva.jose@inifap.gob.mx

2. DEVELOPMENT OF TREE-RING CHRONOLOGIES

In the last few years the interest to develop a network of tree-ring chronologies in Mexico has grown. An important factor has been the funding provided by domestic and international institutions to research projects dealing with tree rings and paleoclimatic studies. Derived from these efforts the first Laboratory of Tree-Ring Research has been established (http://www.inifap.gob.mx/contenido/cirs/cenids/dendrocrolologia.htm) in Mexico. Some of the produced chronologies have been used to reconstruct seasonal precipitation for different sites along the country, streamflow reconstructions, and historical analysis of atmospheric circulatory patterns. The number of tree-ring chronologies currently developed is over 30 and some others are in still in process. Most of the chronologies are less than 600 years long but some of them cover the last thousand years (Figure 1).

Figure 1. Network of tree-ring chronologies developed for Mexico.

The most common species used to produce tree-ring series in Mexico have been Douglas-fir, Montezuma baldcypress, pinyon pine, and other pine species (Figure 2), however, given the high biodiversity of Mexico there is a great potential to increase the number of species suitable for this purpose, including some proper of tropical and subtropical environments.

Figure 2. A 1300 years old cypress tree located at Los Peroles, San Luis Potosí. This riparian species is of great importance for summer precipitation reconstructions. The ahuehuete, sabino or Montezuma baldcypress is the national tree of Mexico.

3. SEASONAL PRECIPITATION RECONSTRUCTIONS

One of the longest seasonal precipitation reconstructions ever developed for northern Mexico is the one reported by Cleaveland *et al*. (2003) for the Durango state. This winter (November - March) rainfall reconstruction extends for the period 1386 - 1993 and shows the presence of intensive and extended droughts that affected this region. Severe droughts were reconstructed for the periods 1540 – 1579, 1751 – 1765, 1798 – 1810, 1850 – 1860, and 1950 – 1965. Some of these droughts like the one taken place in the period 1540 – 1579 has been related to epidemic outbreaks that depleted native human population in the Valley of Mexico after the Hispanic colonization (Acuña-Soto *et al*., 2002; Therrell *et al*., 2004). The drought of the 1950´s has been the most intense in the 20th century and produced severe economical loses all over Mexico

Another winter-spring (october – may) precipitation reconstruction is the one developed for the area of northeastern Chihuahua and eastern Sonora with an earlywood Douglas-fir chronology. This reconstruction extends for 531 years (1472 – 2002) and shows similar droughts to the ones detected in Durango (Figure 3). The importance of this reconstruction is that is the first one developed for a highly productive region in terms of agriculture, livestock, and industry; however, productivity of this area strongly relies on the water yielded in the upper watersheds of the Sierra Madre Occidental. The drought of the 1990´s has affected water availability for different economical uses and even for human consumption. Depletion of the aquifers due to excessive water withdraw has produced additional problems such as sea water intrusion, affected the water quality, and produced an increase in soil salinity, decreased crop productivity and increased costs of production (Ortiz *et al*., 2003). The long-term analysis of low frequency events that characterizes this region is of main importance to plan for sustainable management of limited water resources in northwestern Mexico.

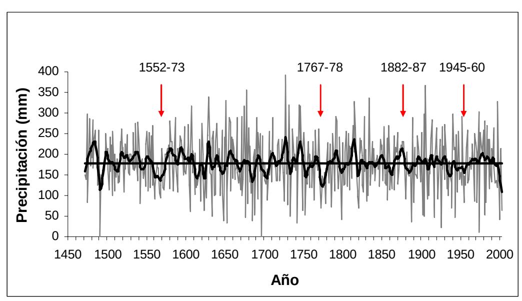

Figure 3. Seasonal winter-spring (october – may) reconstructed precipitation, period 1472 – 2002 for northeastern Chihuahua and eastern Sonora. The mean for the reconstructed period is 143.2 mm with a standard deviation of 52.4 mm. The reconstruction shows recurrent droughts for

the periods 1488-1496, 1552–1573, 1611-1626, 1767–1778, 1882–1887, 1945–1960, and 1993-2002; pluvials were observed for the periods 1477–1486, 1590–1598, 1649–1661, 1736–1750, 1820–1824, 1873–1878, 1940–1944, and 1972-1979. A smoothed spline curve (black bolded line) has been fitted to the reconstruction to emphasize decadal low frequency events.

In northeastern Mexico a winter-spring precipitation reconstruction was developed for Saltillo, Coahuila. In doing this reconstruction five earlywood Douglas-fir chronologies developed along the Sierra de Arteaga range were used. The reconstruction is 342 year long (1659 – 2001) and shows the presence of extended droughts in the periods 1720-1740, 1690´s, and 1670´s (Figure 4). Historical documents for the region indicate that these droughts were commonly associated to limited availability of grains, famine, and presence of epidemic diseases (Cuellar, 1979; García, 1997). Along the 20th century droughts have been better documented and the socioeconomical impacts have been increased which is due to an increased water demand and also to the establishment of settlements in sites prone to droughts.

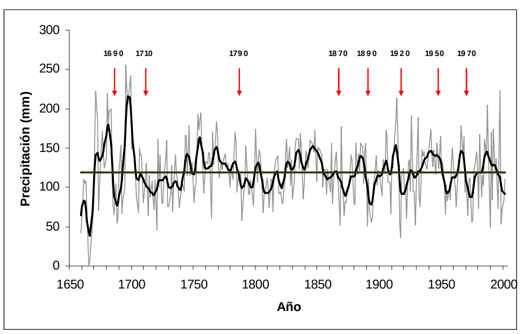

Figure 4. Seasonal winter-spring (january-june) reconstructed precipitation for the period 1659-2001. A smoothed spline line was fitted to the reconstruction to emphasize low frequency decadal events. Severe droughts were detected in the 1660´s, 1680´s, 1710´s, 1800´s, 1870´s, 1890´s, 1910´s, 1950´s, and 1970´s.

The drought episodes present in the Saltillo reconstruction were also found in Cuatrocienegas, Coahuila, a natural protected area rich in endemic species. Some of the droughts detected in this reconstruction took place in the 1740´s, 1790´s, 1860´s, 1900´s, 1950´s, and 1990´s; although the most severe and prolonged dry episodes were those for the periods 1850-1860 and 1950-1960. The need for historical climatic data is urgent for this area that requires hidroclimatic information to plan for the proper use of the limited water resources to preserve this unique ecosystem (Souza *et al.*, 2005).

Another precipitation reconstruction for northeast Mexico is the one developed for the south-central Nuevo Leon and eastern Tamaulipas region. In developing this reconstruction an earlywood *Pseudotsuga menziesii* chronology from a site in Peña Nevada, Nuevo Leon was used.

The reconstruction indicates recurrent droughts affecting the region along 602 years (1400 – 2002) of the reconstruction (Figure 5).

In the 20th century the most significant droughts took place from 1968 to 1975 and from 1952 to 1956. Dry episodes were also detected for the periods 1857-1868, 1785-1790, 1738-1743, 1559-1590, 1526-1536, and 1439-1455. Wet episodes were present in each century, although, the most significant pluvials were detected for the periods 1900-1905, 1740-1747, and 1459-1467. Previous to the 20th century, historical documentation is poor for this region and most of it comes from the Valley of Mexico; nevertheless many dry episodes affected simultaneously extensive areas, thus, the 1448-1454 drought that affected water availability for the “Gran Tenochtitlan” was also observed in this reconstruction. Other common droughts are the ones for the 1860´s, and 1950´s, present in central, northern Mexico and southwestern USA (Fye *et al*., 2003).

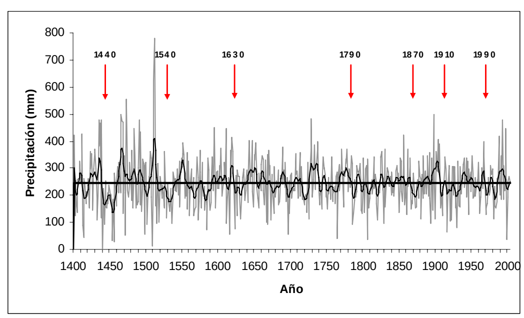

Figure 5. Seasonal winter-spring (december-april) precipitation for 603 year long (1400-2002) reconstruction for the region of south-central Nuevo Leon. A smoothed spline line has been fitted to the reconstruction to emphasize low frequency decadal events. Severe droughts were observed for the 1410´s, 1450´s, 1500´s, 1570´s, 1630´s, 1790´s, 1810´s, 1870´s, 1910´s, 1960´s, and 1980´s.

4. Precipitation reconstructions and ENSO influence

Winter precipitation in northern Mexico and southwestern United Status is significantly influenced by ENSO indices (Ropelewski and Harper, 1989). This relationship is recorded by tree rings and specifically by the earlywood of *Pseudotsuga menziesii* and other conifers growing along the Sierras Madre Occidental and Oriental. The ENSO teleconecction in northern Mexico is significant but its duration and intensity changes through time (Cleaveland et al. 2003). This instability is observed by comparing the reconstructed precipitation and the Tropical Rainfall Index (TRI), an estimative of the ENSO variability that uses precipitation anomalies in the central Pacific and is considered more stable than the Tahiti-Darwin pressure differences (Wright, 1979).

The precipitation reconstruction for the Chihuahua region and the TRI for the period 1896-1995 showed changing correlation values for 20-year subperiods with values in the rank from 0.2 to 0.69. Lower correlations values were observed for the Nuevo Leon and Saltillo precipitation reconstructions. Cold fronts, tropical storms, and other circulatory patterns from the Gulf of Mexico may influence in a greater extent the precipitation in northeastern Mexico

5. HISTORICAL TRENDS OF LOW FREQUENCY EVENTS FOR THE PRECIPITATION RECONSTRUCTIONS

Low frequency events were common for most of the precipitation reconstructions. Thus, significant correlations were observed for the common period 1782-1992. The highest correlations, however were detected for specific reconstructions in a given mountain range. Thus, precipitation reconstructions in the Sierra Madre Occidental were highly significant among them but correlations decreased when they were compared to reconstructions developed for sites in the Sierra Madre Oriental. This result is an indication that physiographic characteristics and specific circulatory patterns may explain the precipitation for a specific region. Winter-spring precipitation in northern Mexico is influenced by the ENSO warm phase, on the other hand precipitation in northeastern Mexico seems to be influenced by cold fronts, tropical storms and other circulatory patterns developed in the Gulf of Mexico. Even though circulatory patterns could be specific for a given region, common dry and wet episodes were common for northern and eastern Mexico. Specific cases are the droughts of the 1810´s, 1860´s, 1870´s, and 1950´s (Figure 6). These common events could be attributed to the influence of general circulatory patterns such as ENSO. A better knowledge of historical climate is required to have a better understanding of these circulatory patterns. Currently, the network of tree-ring chronologies is in process of adding more chronologies, and this endeavor will allow a better understanding of the climate in Mexico for the last millennium.

6. CONCLUSIONS

The historical understanding of climate variability in Mexico is basic to promote sound management strategies for limited water resources and conservation of renewable natural resources

The winter-spring precipitation reconstructions show high inter-annual and multi-annual hidroclimatic variability in the last 500 years. Dry episodes recorded in the 20th century were exceeded by more severe and prolonged episodes in previous centuries, which is an indication that we should plan in advance to prevent the negative effects of extreme events present on the reconstructions.

Most of the precipitation reconstructions reported in this study are affected by ENSO in the winter season, but summer reconstructions are required to analyze the effect of the North America Monsoon System (NAMS), and other circulatory patterns. The development of a more complete network of tree-ring chronologies is in process and is basic to improve our understanding of historical climate in Mexico.

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