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Tree-ring analysis of winter climate variability and ENSO in Mediterranean California(*)

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Summary. — The feasibility of using tree-ring data as a proxy for regional precipitation and ENSO events in the Mediterranean region of California is explored. A transect of moisture-sensitive tree-ring sites, extending from southwestern to north-central California, documents regional patterns of winter precipitation and replicates the regional response to ENSO events in the 20th century. Proxy records of ENSO were used with the tree-ring data to examine precipitation/ENSO patterns in the 18and 19th centuries. Results suggest some temporal and spatial variability in the regional precipitation response to ENSO over the last three centuries.

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1. – Introduction

Central and southern California contain only 10% of the global area classified as Mediterranean climate, and although a relatively small area, the region is extremely important for its agriculture. California leads the United States in agriculture, producing over 50% of the nation's fruits, vegetables, and nuts, and is also the nation's biggest farm products exporter. The high agricultural productivity is in large part due to the Mediterranean climate. Since much of the land is irrigated, with a reliance on water supplies primarily from Sierra Nevada watersheds, the region is vulnerable to the regional impacts of global climate change. Projected warming will lead to greater water demand from a supply that is already being affected by earlier snowmelt runoff in the spring [1]. Changes in atmospheric circulation features responsible for the delivery of

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moisture could also impact this region. Most of central and southern California' s annual precipitation falls between November and April. El Niño/Southern Oscillation (ENSO) events have significant impacts on winter precipitation in this region. In general, El Niño events brings above average precipitation to the entire region, while La Niña events have a more variable impact on regional precipitation. During La Niñas, the southern coast is most often dry while the northern coast tends to be wet. However, the spatial rainfall response is highly variable from event to event. Because of the short instrumental record, it is difficult to determine whether there are decadal-scale variations in the relationship between regional precipitation and ENSO. Understanding low-frequency changes in the character of ENSO and their influence on California climate are important for anticipating possible future impacts resulting from long-term climate change. Understanding the range of natural variability from instrumental, historical, and palaeoclimatic data, along with model projections of future climate will aid anticipation of the range of conditions that may be expected in California's Mediterranean region. In this study, the feasibility of augmenting instrumental and historical records with tree-ring data as a proxy for both regional precipitation and ENSO events to document the relationship between ENSO and winter precipitation over three centuries is explored.

2. – Data

Modern instrumental data for California climate divisions 1 and 2 (northern California), 4 and 5 (central California), and 6 (southern coastal California) were obtained from the National Climatic Data Center for the years 1896-2003. Precipitation for the months November through April were totaled to represent the winter wet season. Data were standardized to facilitate comparison. ENSO event years were taken from the list of years compiled by the NOAA Climate Diagnostic Center for 1948-1999. A longer list of ENSO events was generated from the ranked seasonal Southern Oscillation Index (SOI), 1896-1995, using the years with the highest and lowest 20 values for both winter (December-February) and spring (March-May). Exceptions were made in three years where one season ranked in the highest or lowest 20 and the other season fell within the highest or lowest 26 values. Tree-ring data and reconstructions of ENSO variability were used to augment instrumental data and to extend records back to the 18th century. A transect of moisture-sensitive tree-ring chronologies was selected from the International Tree-Ring Data Bank [2] that extends from southwestern to north-central California, encompassing the Mediterranean region. Initial selection was based on species known to be sensitive to moisture. These included two species of oak, *Quercus douglasii* and *Quercus lobata* [3], the three conifers, *Juniperus occidentalis, Pinus ponderosa*, and *Pseudotsuga macrocarpa*. Additional screening was based on tree-ring chronology length and correlation with divisional precipitation. A network of 16 tree-ring chronologies resulted that was well-correlated with divisional November-April precipitation, with a common time period from 1710-1982. Thirteen of the 16 chronologies extended to 1995 or later. The chronologies are in the form of standardized indices of growth which have had low-order persistence related to biological factors removed. The chronologies were then normalized so that the mean value for all of the chronologies is zero. ENSO proxy data were obtained from three different reconstructions (Niño3 [4, 5]; SOI [6]). The Niño3 [4] and SOI [6] reconstructions were generated from tree-ring data from Mexico, the south-central and southwestern US, and in the case of the SOI, from Indonesia. The Niño3 reconstruction [5] was generated from seasonally-resolved reconstructed global surface temperature patterns derived from tree rings, ice cores, corals, and historical climate data. All three

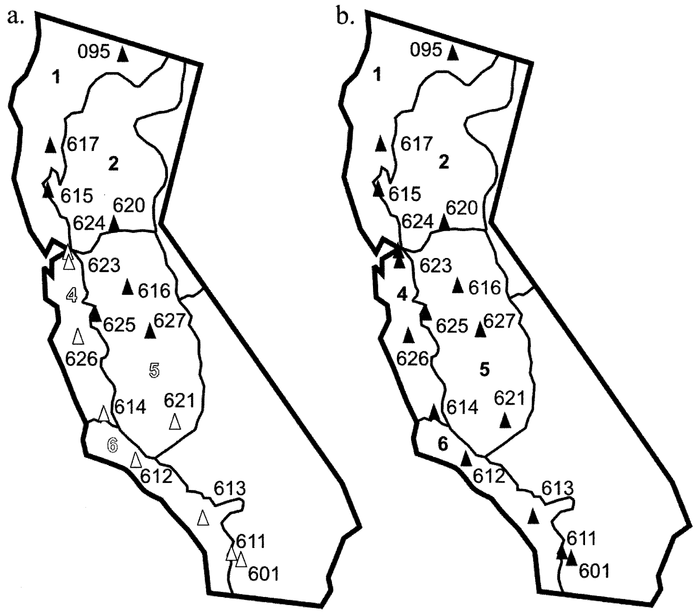

Fig. 1. – Maps showing climate divisions (1, 2, 4, 5, and 6) and locations of tree-ring chronology sites with site numbers (triangles). a) For La Niña years, sites with above average growth are indicated with dark triangles and with below average growth by light triangles. Divisions with above average winter precipitation are indicate with bold type and with below average winter precipitation with light type. b) For El Niño years, sites with above average growth are indicated with dark triangles and with below average growth by light triangles. Divisions with above average winter precipitation are indicate with bold type and with below average winter precipitation with light type.

records reflect winter (December-February) or boreal cool season (October-March) conditions. A list of the strongest ENSO events was compiled by comparing the three record for the years 1706-1899 and selected the years with extreme values (20th and 80th percentiles) in all three records. Some exceptions were made for highly ranked values in two of the three records, particularly for La Niña events which were not shared as often (five additional years). Validation of these dates was partially accomplished with a Niño 3.4 index from [7] reconstructed sea surface temperatures compiled by [8], for the years 1856-1899. Several other event years were added (two El Niño and two La Niña) as a result of this validation process (these tended to be high ranking in two of three proxy records) and one year was deleted. The resulting list contained a total of 21 La Niña and 25 El Niño events which likely represent the strongest events, but not all events (weaker events were not considered).

3. – Relationship between winter precipitation, ENSO events, and tree-ring data

The set of tree-ring chronologies was correlated with total winter precipitation for each of the climate divisions. The strongest associations between each chronology and the divisional data were typically with the division in which the chronology was located, or a neighboring one. The highest correlations between precipitation and tree growth overall were with chronologies located in the center of the region. Significant correlation existed between all chronologies and each of the division except between those that were most distant (*e.g.*, chronologies in division 6 with precipitation in divisions 1 and 2). These patterns closely match those displayed by the correlations between divisional data and demonstrate the ability of the tree-ring data to reflect regional winter precipitation. Composite maps for winter precipitation anomalies by division for La Niña and El Niño events (eight events each, 1948-1999) from the NOAA Climate Diagnostics Center show that El Niño winters are generally wet over the entire study region, while La Niña winter precipitation anomalies are more spatially heterogeneous. Winters in the northern part of the state tend to be wetter than average, the central part is somewhat dry, and the southern coastal region is very dry. When the tree-ring chronology growth index values are averaged for these same El Niño and La Niña years, the spatial pattern of above and below average growth can be compared to the pattern of precipitation anomalies. The tree-growth patterns generally match the precipitation anomalies for the La Niñas, with higher growth in the northern region, and lower growth elsewhere. The lowest growth is found in chronologies located somewhat further north than the driest precipitation. Most of the chronologies reflect above average growth during El Niño winters, but three northern sites show slightly below average growth. A longer analysis period, 1895-1995, allows a more complete examination of the relationships between ENSO, regional precipitation, and tree-growth. Divisional precipitation and tree-growth indices were averaged for 13 La Niña and 12 El Niño events. The average spatial pattern in the precipitation data, below average precipitation in the central and southern division, and above average in the northern divisions in La Niña years and above average precipitation in all regions in El Niño years, is the same as for the shorter time periods and was matched fairly well in the tree-ring data (figs. 1a and b). The degree to which events showed widespread precipitation anomalies was also examined. In five of the La Niña years, dry conditions were very widespread (across four or five of the five divisions). Four of these same years reflected widespread low growth in the tree-ring chronologies (11 to 14 of the 16 chronologies). The same widespread precipitation El Niño years were also shared by the tree-ring data, but several other years showed widespread growth but not widespread wet conditions. Overall, these results indicate that the chronologies reflect the average regional precipitation anomaly patterns associated with ENSO, as well as the spatial extent of the most extreme individual events. This analysis also indicates the high degree of variability in precipitation and tree-growth response to ENSO events, both spatially and temporally.

4. – Relationships between ENSO events and regional winter precipitation from proxy data

In order to assess the representativeness of the spatial patterns of ENSO response in Mediterranean California for a longer period of time than afforded by the instrumental data, the next part of the analysis used the tree-ring chronologies as proxies for winter precipitation, and the ENSO events compiled from three proxy records. Spatial patterns of tree growth, representing above and below average moisture were assessed for ENSO event years from 1706-1899. These results were evaluated with ENSO events from instrumental data and tree-ring data for the 20th century for a total of 34 La Niña and 36 El Niño event years. In general, the regional response to ENSO events over the past three centuries shows a high degree of spatial and temporal variability, as seen in the

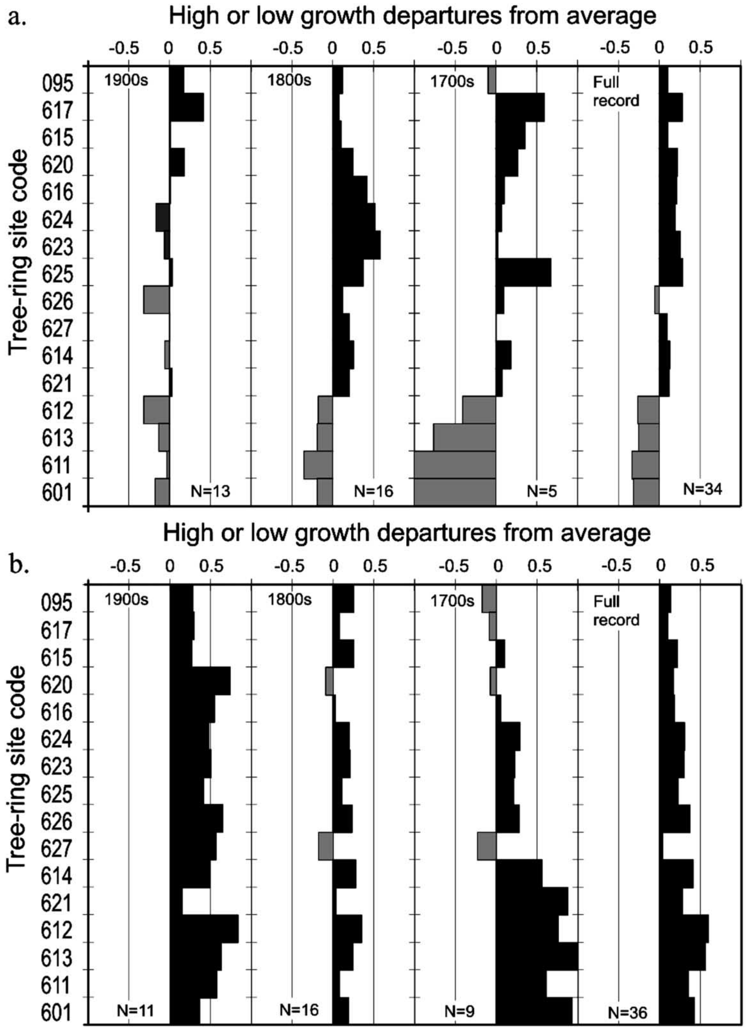

Fig. 2. – Tree-growth departures by site by century (first three columns) and for full period. Sites are arranged from north to south. a) La Niña years, b) El Niño years.

instrumental record. The response to La Niña events is less spatially cohesive than for El Niño events, with the most consistent low growth response in the four southernmost chronologies. When the average response to La Niña events is assessed by century, some variations in this pattern emerge (fig. 2a). Although the difference in numbers of events per century complicate direct comparisons, there is a striking difference between the patterns for the full, 19th, and 18th century patterns and the 20th century pattern. In the full, 19th, and 18th century periods, the negative response is almost exclusively confined to the four southernmost chronologies, while in the 20th century, this response is weaker but spreads up through the central region. It is possible that some of this difference comes from the selection of the 20th century events from the instrumental record, so these events are the strongest 20% of event years in the century, while the others are

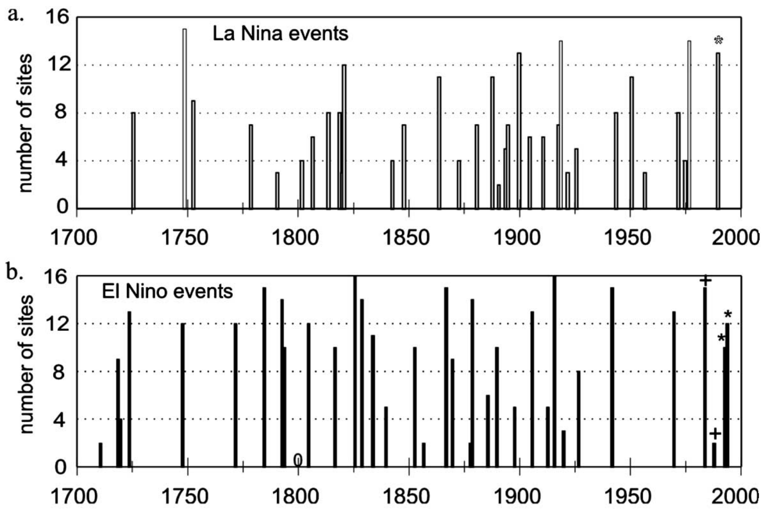

Fig. 3. – Spatial extent of tree-growth anomalies in ENSO event years based on a total of 16 sites, except where noted. Years with only 15 sites are indicated by an asterisk, years with only 13 sites are indicated by a plus sign. a) La Niña event years, b) El Niño years.

the strongest 20% of event years in the 18th and 19th century, and clearly, these are not evenly distributed over time. Another difference is the more marked positive response in the 19th century in the northern part of the central region, and a more marked positive response in the north in the 18th century, relative to other centuries. Above average growth is more evenly spread across the chronology network during El Niño event years, with average growth for all years above average, as in the instrumental period (fig. 2b). When examined by century, the spatial pattern for the 20th century bears a close resemblance to the full period. The 19th century appears the most different, with a weaker response compared to other centuries and compared to the response during La Niña years. The 18th century response has more of a gradient that in other centuries, with a strong positive response in the south, moderate positive in the central region, and a weak negative response in the north. The spatial extent of the tree growth response to ENSO events was assessed for the three centuries by plotting the numbers of chronologies with below average growth during La Niña years and above average growth during El Niño years for each event year (figs. 3a and b). In six of the 34 La Niña events years, below average growth occurred in 75% or more of the sites. Three of those years were in the 20th century and one additional year was in 1899. In nine years, 25% or less of the sites had below average growth and these years are concentrated in the 19th century (the century with the most La Niña events). El Niño years with widespread tree-growth response are more frequent and more evenly distributed across time. In 16 years (over 50% of the events), growth is above average at 75% or more of the sites. Although these years with widespread growth anomalies are distributed evenly across the three centuries, five of the years are consecutive events in the 18th century. There are relatively few years (seven) with growth anomalies at 25% or less of the sites, but for one of these years, 1800, no site shows above average growth.

5. – Conclusions

Mediterranean California winter precipitation anomalies are influenced by ENSO events. During El Niño events, winters are typically wet throughout the region. In La Niña years, the northern region tends to have above average precipitation, while the central and the southern regions (particularly the southern region) tend to be dry. In both cases, there is variability from event to event. A set of 16 tree-ring chronologies, selected for sensitivity to moisture, reflect well the spatial pattern of winter precipitation in the divisional climate data. These proxy data duplicate the precipitation response to ENSO across the region as well. The 20th century precipitation/ENSO response pattern was evaluated in the context of the past three centuries using proxy data from three reconstructions of ENSO and the set of 16 tree-ring chronologies. The La Niña response is much different in the 20th century, with a weaker but more spatially extensive response than in other centuries. This appears to be, in part, a result of several very spatially extensive events in the 20th century. La Niña-related dryness may have been more intense and focused in the southern part of the region, and central and northern California may have been more often under the influence of a positive precipitation response in 18th and 19th centuries. The overall pattern of the El Niño response is more robust, averaged over centuries, although the strength of the response appears to be variable from century to century. In future work, it would be useful to further validate the proxy ENSO event years with historical or other proxy data as is possible. The impact of the use of a mix of instrumental (20th century) and proxy (18th and 19th centuries) ENSO event years on these results should be evaluated. In addition, this approach could be applied to a larger region to assess larger-scale climate responses to ENSO, over a longer time period where proxy data are available.

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