Tree-Ring Reconstructions of Winter Climate and Circulation Indices for the Southwestern United States

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Introduction

A key to understanding the causes for climate variability lies in understanding how atmospheric circulation influences regional climate. The goal of this research is to investigate the long-term relationships between atmospheric circulation and winter climate in the southwestern United States. Patterns of atmospheric circulation are described by circulation indices, and winter climate is defined as number of days with precipitation and mean maximum temperature for the winter wet season, November though March. Records of both circulation indices and climate variables were reconstructed with tree-ring chronologies for the period 1702-1983. The years of the highest and lowest values of circulation indices and climate variables were compared in order to investigate possible spatial and temporal relationships between extremes in circulation and climate.

Circulation Indices and Reconstructions of Indices

In previous research (Woodhouse, in review), I identified some key circulation features influential to climate for the period of instrumental climate records. A set of circulation indices was compiled that described important circulation features, including the Southern Oscillation Index (SOI), a sea surface temperature (SST) index from the equatorial Pacific, a modified Pacific/North American (PNA) index, and two indices that feature a southwestern low pressure center: the Pacific High/Southwestern Low (PHSWL) and the Southwestern Trough (SWTROF) indices (Table 1). The last three indices were derived specifically for this study. Relationships between circulation, as described by the indices, and climate at a network of stations were then examined. To summarize briefly, negative SOI, SWTROF, and PHSWL values and positive SST and PNA values tend to correspond to wet, cool conditions in the Southwest, while positive SOI, SWTROF, and PHSWL values and negative SST and PNA values tend to correspond to warm, dry conditions.

In: C.M. Isaacs and V.L. Tharp, Editors. 1997. *Proceedings of the Thirteenth Annual Pacific Climate (PACLIM) Workshop, April 15-18, 1996.* Interagency Ecological Program, Technical Report 53. California Department of Water Resources.

Table 1
CIRCULATION INDICES

Index	Description	Source	Interval
SOI	Southern Oscillation Index-sea level pressure; Tahiti - Darwin	Climate Analysis Center (CAC)	Winter (Dec, Jan, Feb); Fall-Winter (Sep-Feb)
SST	Sea surface temperature from COADS data 4°N-4°S, 160°-80°W (1930-1979) 5°N-5°S, 190°-90°W (1980-1990)	Kiladis and Diaz (1989) CAC NINO3 index	Winter (Dec, Jan, Feb)
PNA-modified	Pacific North American patterns; a measure of zonality across North America. Location of pressure centers modified after Keables (1992) PNA3 pattern. PNA=1/3[-Z*(135°W, 35°N)+ Z*(100°W, 75°N)-Z*(70°W, 30°N)]	Woodhouse, in press	Winter (Jan, Feb, Mar)
SWTROF	Southwestern trough; measure of intensity of low over the SW, in combination with high pressure over the Gulf of Alaska and the Great Lakes. SWTROF=1/3[-Z*(140°W, 50°N)+ Z*(115°W, 35° N)-Z*(80°W, 45°N)]	Woodhouse, in press	Winter wet season (Nov-Mar); Early/late winter (Nov, Dec, Mar)
PHSWL	Pacific high/southwestern low; measure of intensity of low over the SW, in conjunction with the longitudinal position of the Pacific high. PHSWL=Z*(115°W, 35°N) — longitude of the greatest 500mb height @ 30°N, 120°-160°W	Woodhouse, in press	Winter wet season (Nov-Mar); Early/late winter (Nov, Dec, Mar)

* Z=standardized 500mb height at each grid point.

A network of 86 tree-ring chronologies located in the Southwest was used to reconstruct the circulation indices, using the technique of principal components regression (Fritts 1976; Cook and Kairiukstis 1990). The 86 tree-ring chronologies were transformed into a set of 12 principal component scores. Scores were lagged forward and back one year. This set of lagged and unlagged component scores comprised the set of 36 independent variables used in stepwise regression to reconstruct the circulation indices. Regression models explained from 26% (SST) to 78% (SWTROF, November-March average) of the variation in the circulation indices. Reconstructions were verified statistically and, where possible, validated with independent data. Reconstructed indices extended from 1702 to 1983.

Climate Reconstructions

The same network of 86 tree-ring chronologies, with two additional ones, was used to reconstruct regional winter climate variables. Climate variables (number of days with precipitation and mean maximum temperature) were reconstructed for each of six regions (California coast; southeastern California and lower Colorado River basin; northern Arizona and New Mexico; southern/central Arizona; central Arizona and New Mexico; and southern Arizona and New Mexico) (Figure 1). As with the reconstructions of indices, a principal components regression technique was used, incorporating lagged and unlagged scores from a principal components analysis on the tree-ring chronologies to generate a set of independent variables for the stepwise regression models. Regression models explained 56-73% of variation in the series of number of precipitation days and 49-79% of variation in the temperature series. As above, reconstructions were verified statistically and validated with independent data.

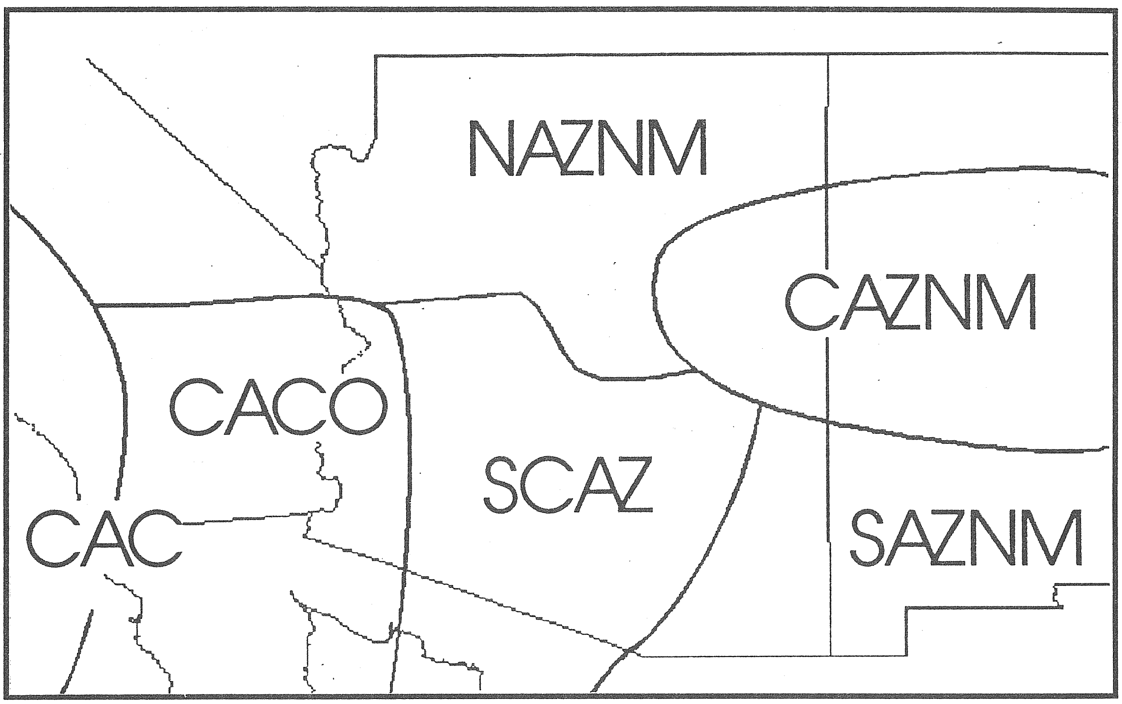

Figure 1 Location of climate regions used in reconstruction of regional climate series.
CAC = California Coast
CACO = California and lower Colorado River basin
NAZNM = Northern Arizona and New Mexico
SCAZ = South-Central Arizona
CAZNM = Central Arizona and New Mexico
SAZNM = Southern Arizona and New Mexico.

Principal Components Analysis of Reconstructed Circulation Indices

A principal components analysis was performed on the set of reconstructed circulation indices. Three components resulted, explaining 83% of total variance and consisting of:

- SOI, SST, and PNA indices
- Two seasonal versions of the SWTROF index
- Two seasonal versions of the PHSWL index.

These groupings suggest that three types of circulation indices may be influential to climate in this area.

Time Series Plots of Years of Extreme Values

Each reconstructed regional climate series and circulation index was ranked, and the years of the highest and lowest 20% of values were identified. Time series plots showing the years of these extreme values for each of the regional climate variables and indices were generated so that relationships could be assessed visually. Plots suggest that:

- For reconstructed numbers of precipitation days and temperature, although there were years of extreme values common to all regions, there were also years when only some of the regions had extreme values. For precipitation day extremes, the two eastern regions (CAZNM, SAZNM) appear to act separately most often. For temperature, the two California regions (CAC, CACO), as well as the two eastern regions, often show years of extreme values in common with each other but not with the other regions. This suggestion of an east/west diagonal division across the study area was also supported by an analysis of the groupings of regions for which the same set of five or more years of extreme values occurred. This split was much more pronounced for the precipitation day series than for the temperature series.
- For reconstructed indices, years of extremes for the SOI/SST/PNA indices occurred fairly consistently over the three centuries, but were most common from 1950 to 1970. Years of extremes for the PHSWL indices were concentrated in the late 1800s and into the 1900s, while years of extreme values for the SWTROF indices were more frequent in the late 1800s and early 1900s.
- Many of the years of extreme values of number of precipitation days and temperature series coincide with years of extremes in one or more of the circulation indices. In some cases, years of extreme values for several of three index types coincide with the same year of an extreme in a climate variable, but frequently only one index type coincided with a year of a climate extreme.

Distribution of Years of Extreme Values by Century

The number of years of extreme values for reconstructed regional precipitation day and temperature series (Figure 2) and reconstructed circulation indices (Figure 3) was tabulated for each century. The percentage of years of extreme values per century was figured to allow for a comparison between centuries (since the 20th century record is not complete). The values were plotted to assess low-frequency changes in number of extreme values over the past three centuries.

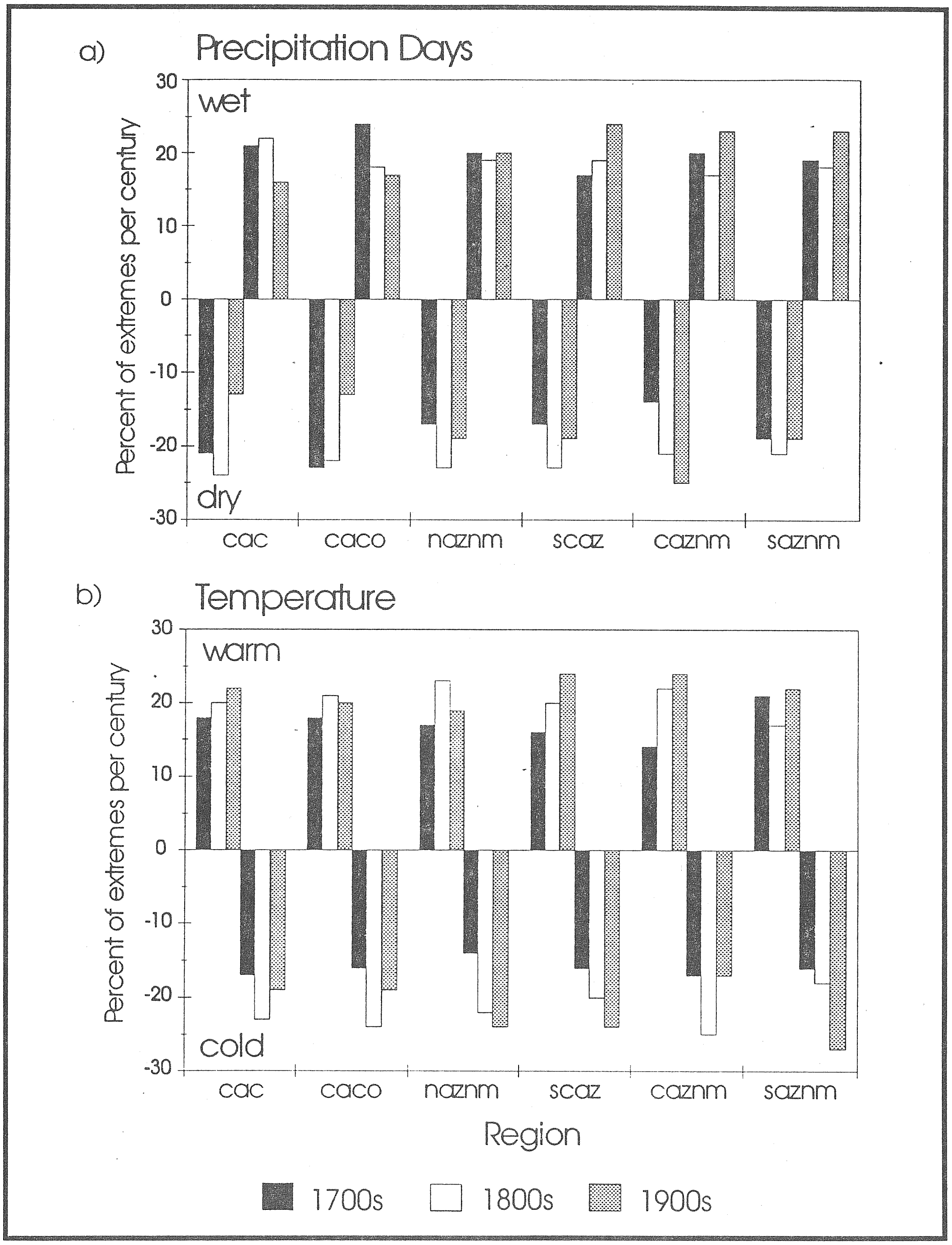

Figure 2 (a) Frequency of years of extreme values (upper and lower 20%) for precipitation day reconstructions.
(b) Frequency of years of extreme values (upper and lower 20%) for temperature reconstructions.

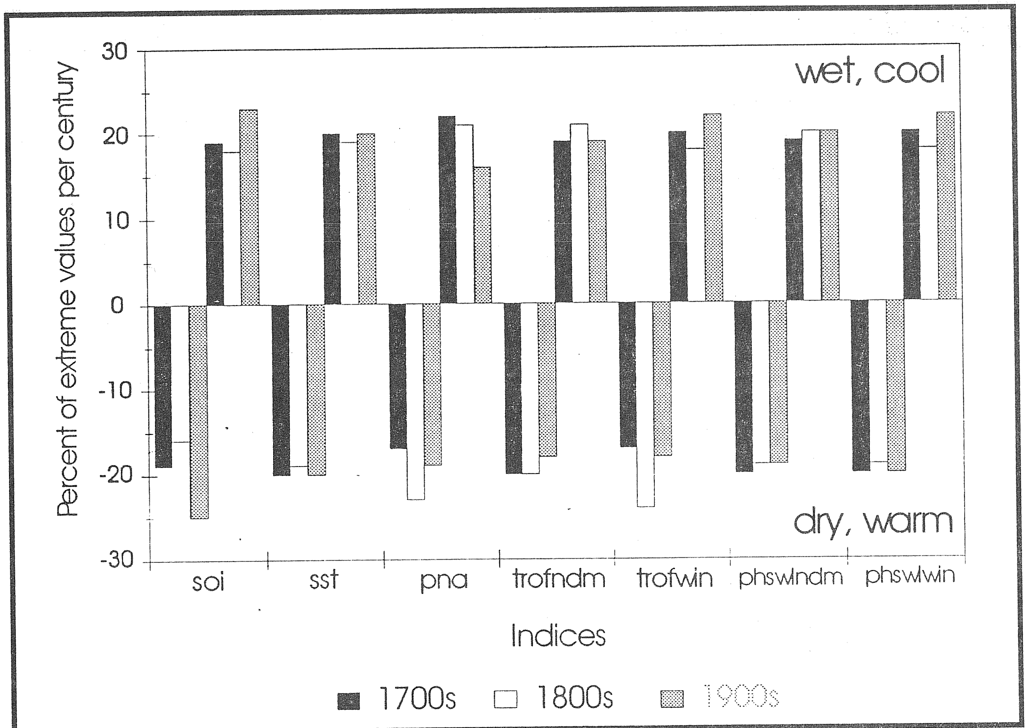

Figure 3 Frequency of years of extreme values (upper and lower 20%) for reconstructed indices. Indices are plotted in the sense that they represent wet/cool and warm/dry conditions.

Results suggest that:

- Years of positive (wet) precipitation day extremes have been more frequent in the 20th century in three eastern regions (SAZNM, CAZNM, SCAZ) but more frequent in the 18th and/or 19th centuries in the two California regions (CAC, CACO). Years of negative (dry) extreme values were also more prevalent in the 18th and especially in the 19th centuries in western and central regions (CAC, CACO, NAZNM, SCAZ).
- Years of warm temperature extremes were more frequent in the 20th century in most regions (except CACO, NAZNM), as were cold extremes in the central and southern regions (NAZNM, SCAZ, SAZNM). In the California regions, years of cold extreme temperature were more frequent in the 19th century.
- For the reconstructed indices, the number of years of extreme SOI values (both warm/dry and cold/wet extremes) is greater in the 20th century than in the previous two centuries. Years of PNA extreme values were more numerous in the previous centuries (18th and 19th centuries for cold/wet extremes, 18th century for warm/dry extremes). Years of warm/dry extremes for the TROF (November-March average) index were more prevalent in the 19th century.

Summary

Reconstructions of regional climate variables (number of days with precipitation and mean maximum temperature) and circulation indices have been produced for the period 1702-1983. A principal components analysis on the reconstructed circulation indices identified three groupings of indices: SOI/SST/PNA indices, SWTROF indices, and PHSWL indices.

An examination of the years of the highest and lowest 20% of values for the climate reconstructions suggests that distribution of years of extreme values has been spatially and temporally variable over the past three centuries. The distribution of years of index extremes has been temporally variable as well.

An analysis of the frequency of years of extreme values by century suggest some possible links between climate extremes and circulation index extremes. The coincidence of an increase in years of SOI extremes in the 20th century and an increase in years of precipitation day extremes in the eastern part of the study area implies a possible relationship, especially during years of wet extremes. A higher frequency of years of warm temperature and low precipitation day extremes in some of the central regions (especially NAZNM) in the 19th century coincides with an increased number of years of warm/dry extremes in the Southwestern trough index, also in that century, suggesting a link. Further research may help elucidate these relationships.

Acknowledgement

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