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Tree-Ring Extension of Precipitation Variability at 12-km Grid Points in Eastern Nevada: Implications for Drought Analysis

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1. Introduction

Preparing for future hydroclimatic variability benefits from an assessment of the duration, magnitude, and intensity (or peak value) for both dry and wet spells. Given that climatic episodes recorded by the instrumental record are not likely to cover the entire spectrum of potential future scenarios (Milly *et al.*, 2008), water managers can "hedge their bets" by examining long (*i.e.*, multi-century) proxy records of climate at seasonal to annual time steps (Biondi and Strachan, 2012). Until recently, these records were only available at relatively coarse spatial scales, such as the 2.5×2.5° grid spacing of the North American Drought Atlas (Cook and Krusic, 2004). However, km-scale spatial intervals can now be achieved using a combination of more intense sampling and advanced statistical techniques. In particular, kriging is a geostatistical technique commonly used for optimal interpolation of environmental data (Isaaks and Srivastava, 1989), and space-time geostatistical models can improve kriging estimates when long temporal sequences of observations exist at relatively few points on the landscape (Christakos, 2000).

In the Great Basin of North America, ecotonal environments characterized as lower forest border sites are ideally suited for tree-ring reconstructions of hydroclimatic variability. I present here how space-time kriging was applied to a network of 22 precipitation records developed from single-leaf pinyon (*Pinus monophylla*) tree-ring samples in eastern Nevada, within the Great Basin of North America (Figure 1).

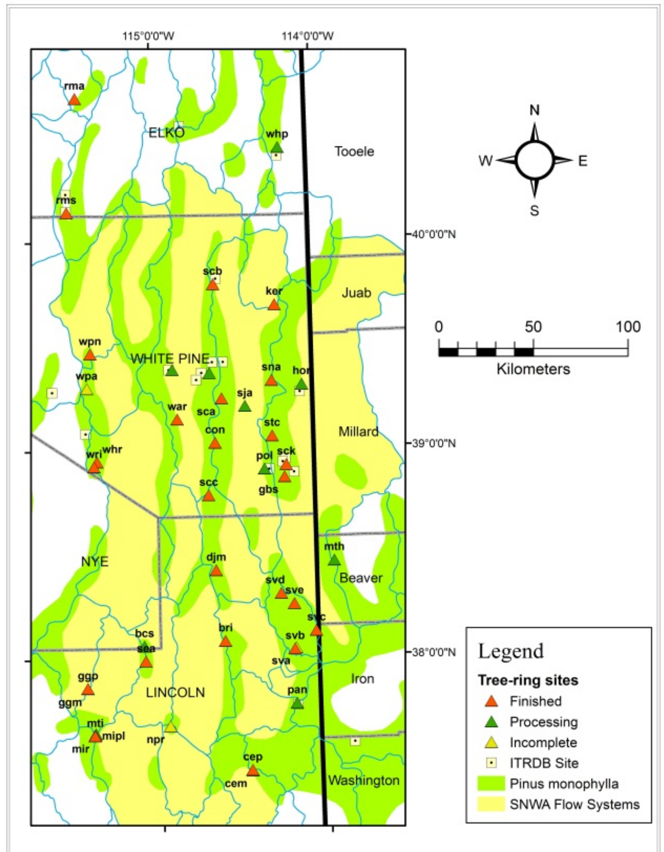

Fig. 1 Map of the study area, showing the Nevada-Utah border (heavy vertical line), county lines (gray lines) and names (uppercase), subwatershed boundaries (blue lines), distribution of single-leaf pinyon pine (*Pinus monophylla*, green areas), location of tree-ring sites (lowercase 3-letter codes), either new (triangles) or from the ITRDB database (squares), and hydrographic basins of interest to the Southern Nevada Water Authority (SNWA Flow Systems).

2. The tree-ring network and precipitation reconstructions

A total of 22 tree-ring sites (5 from the ITRDB dataset) in eastern Nevada distributed over 500 m of elevation (~1930-2430 m) and a geographical area of ~ 230 (N-S) × 155 (E-W) km were selected based on

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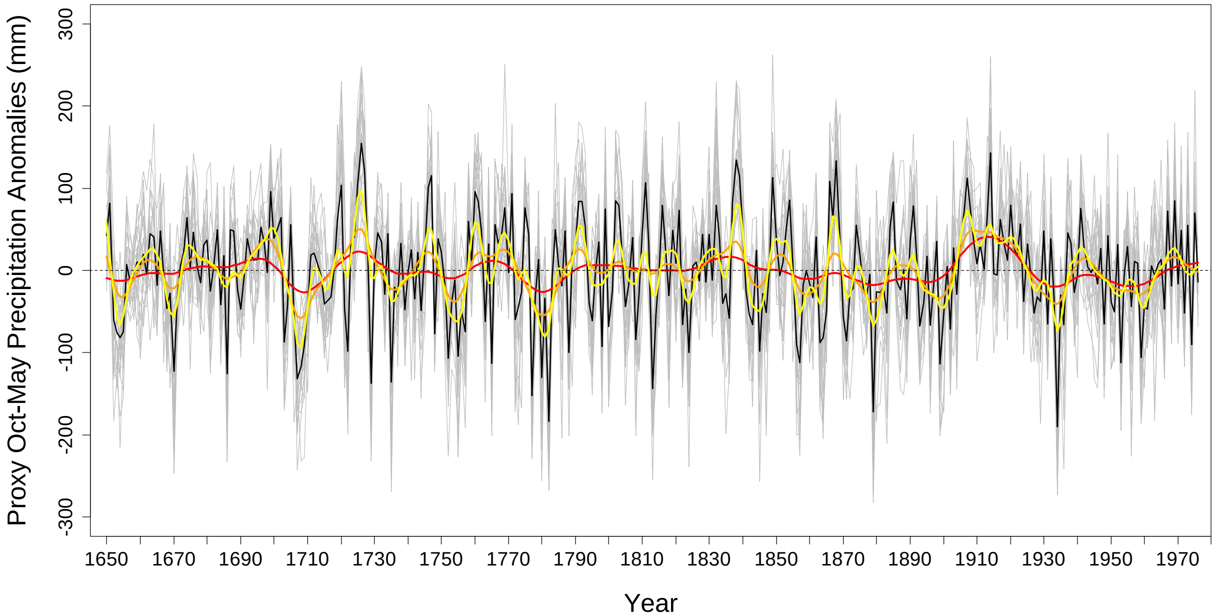

Fig. 2 The average (black) of the 22 site reconstructions (gray) of October-May total precipitation anomalies (mm) was smoothed with a 30-year (red), 15-year (orange), and 7.5-year (yellow) cubic spline to highlight interannual and interdecadal patterns.

their correlation with local precipitation data obtained from the PRISM 4 × 4 km database (Daly *et al.*, 1994). Each site tree-ring chronology was computed as follows:

$$\overline{I}_t = \underset{i=1,\ldots,n_t}{median}\left(\frac{w_t}{y_t}\right)_i$$

where $\bar{I}_t$ = chronology value in year t = median annual index; n_t = number of samples in year t, with $n_t \geq 3$; w = crossdated ring width (mm, with 1000th digit resolution) of sample i in year t; y = value of sample i in year t computed by fitting a cubic smoothing spline with 50% frequency response at a period of 100 years to ring width series i; w_t / y_t = index value of sample i in year t. Site chronologies were obtained by fitting a cubic smoothing spline (Cook and Peters, 1981) to each ring-width series to avoid known issues that affect other types of standardization functions, such as modified negative exponentials (Biondi and Qeadan, 2008).

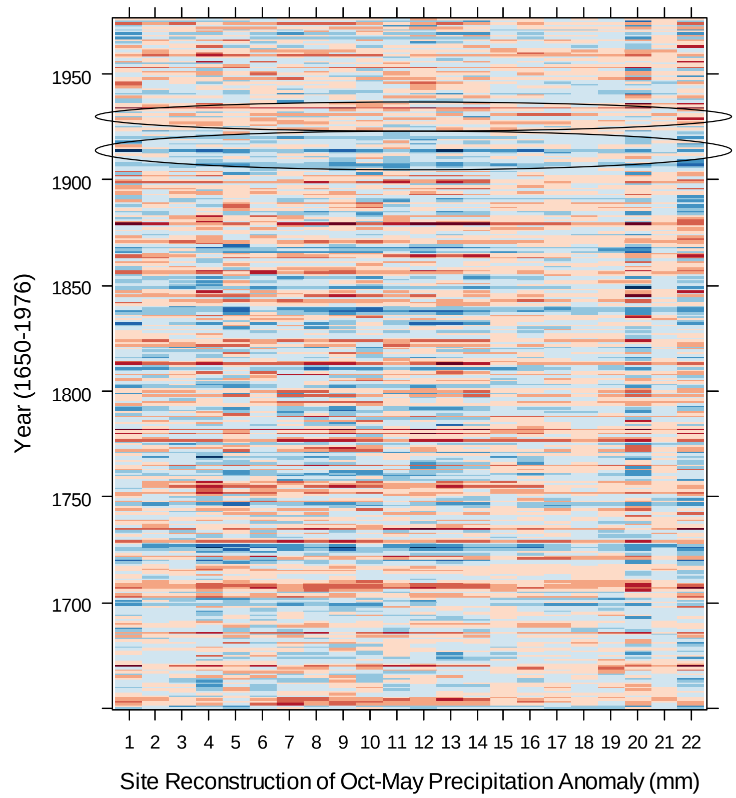

Fig. 3 Pseudo-color plot of the 22 reconstructions of October-May total precipitation anomalies, showing temporal patterns at annual resolution (y-axis). The color scale for the anomalies, divided into 10 intervals over a 600-mm range, is displayed on the right. The early 1900s pluvial and the "Dust-Bowl" drought that followed it were highlighted with black ellipses.

The period in common among all tree-ring chronologies, *i.e.* 1650-1976, was used to reconstruct October-May total precipitation using the Line of Organic Correlation (LOC) method (Biondi and Strachan, 2011). The LOC method was used because it maintains the variability found in the instrumental record (Helsel and Hirsch, 2002), and is particularly well adapted to reproduce long-term features of hydroclimatic anomalies (Figures 2 and 3).

Individual, annually resolved site reconstructions were then combined using spatio-temporal kriging to produce 327 annual maps (from 1650 to 1976) on a 12 × 12 km spacing, for a total of 315 grid nodes. I performed space-time estimation (Fassó and Cameletti, 2009) using public-domain software (R Development Core Team, 2012). Elevation was treated as a covariate in order to compute a single kriging estimate for each two-dimensional grid point location (rather than predict over all possible altitudes), and still take elevation into account. Inter-annual patterns at the km-scale were quantified by the duration, magnitude, and intensity (peak value) of past episodes (as done by Biondi *et al.*, 2008). By considering how modern interannual variability compares to that of previous records, recent changes can be placed in a long-term context to estimate the likelihood of severe and sustained drought.

3. Space-time interpolation and drought analysis

Space-time variograms showed an exponential behavior up to about 200 km with no temporal autocorrelation, *i.e.* beyond the 1-year lag the spatial dependence was essentially zero. The annual mean of the 315 grid point estimates was used to identify wet and dry episodes. The three driest years were 1934, 1879, and 1782, and the three wettest years were 1914, 1868, and 1726 (Figure 4). Greater spatial variability

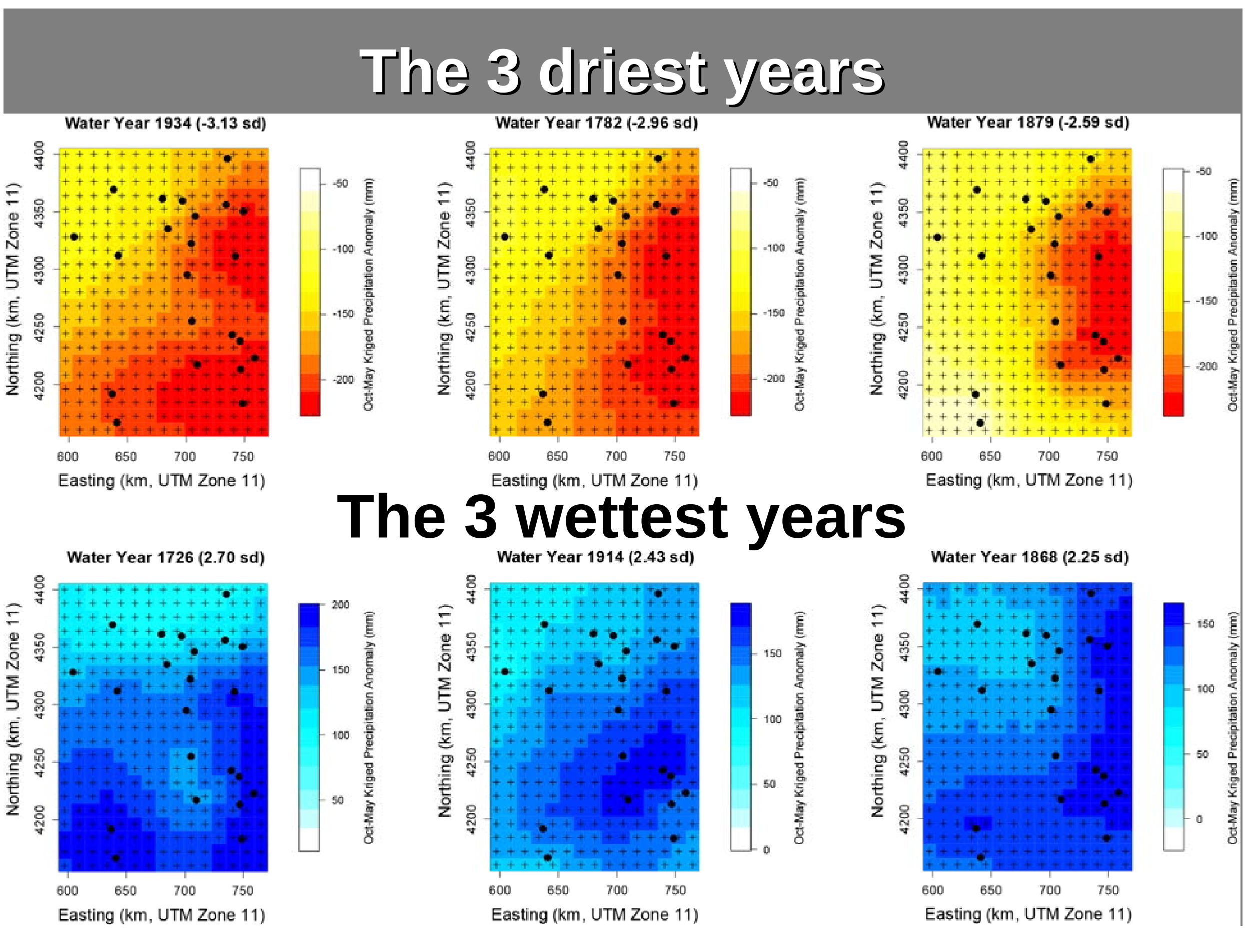

Fig. 4 Pseudo-color plots for space-time interpolated reconstructions of October-May total precipitation anomalies (mm). The color scale for the anomalies, divided into 12 intervals over a 190-mm range, is displayed on the right. The location of tree-ring chronologies (solid black circles) and 12-km grid points (black crosses) is also shown.

emerged during wet periods, whereas dry spells were more synchronous over the landscape. At the annual time scale, the most remarkable episode in the entire reconstruction was the early 1900s pluvial, followed by the late 1800s drought. The 1930s 'Dust Bowl' drought was in 8th position, making it a remarkable hydro-climatic episode for at least the past few centuries. After smoothing the annual values with a 7.5-year cubic spline to emphasize interannual variability, the early 1900s pluvial remained the strongest episode, but the 1930s drought became the second strongest one. Therefore, the early-1900s pluvial, a most remarkable episode in the last few centuries, biases the instrumental record, but water management policies in eastern Nevada basins could use the 1920-30's drought as a relevant worst-case scenario.

Besides showing how regional drought severity varies across the Great Basin, these results directly address the needs of water managers with respect to planning for 'worst case' scenarios of drought duration and magnitude. For instance, it is possible to analyze which geographical areas and hydrographic basins are more likely to be impacted during the most extreme droughts, at annual or multiannual timescales AND at the km-spacing used by regional climate models. This approach allows water managers not only to evaluate drought patterns for single watersheds, but also to determine if episodes that occurred during the instrumental period can be used for long-term planning, thereby increasing their ability to design management practices aimed towards resiliency to future changes.

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