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Comparing tree-ring based reconstructions of snowpack variability at different scales for the Navajo Nation

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ABSTRACT

Snowpack in the western U.S. is on the decline, largely attributed to increasing temperatures in the region. This is a critical issue for many Native American communities who disproportionately rely on local snow-fed water supplies. In light of a combined ongoing drought and limited climate information for the Navajo Nation, Navajo water managers face decision-making challenges complicated by past and future climate uncertainty. Developed in partnership with the Navajo Nation Water Management Branch, this study documents two snowpack reconstruction options to address Navajo concerns about the amount and variability of snowpack in the Chuska Mountains. We used two separate snowpack datasets with tree rings collected in northern Arizona to develop and evaluate reconstructions of Chuska snowpack and their potential relevance and usefulness to Navajo water managers' decision-making. We found that both reconstructions skillfully estimated snowpack, though there were differences that may have meaningful implications for water managers. Major snow droughts occurred roughly once per century over the last 300 years, with droughts in 1728–1744, 1818–1834, 1950–1977, and 1999–2006. Extremely dry individual years in each reconstruction punctuate multi-year drought periods in a way that has not been recognized from instrumental data alone and that can have a large influence on the overall intensity of a given drought. The reconstruction that is most representative of Chuska snowpack has less explanatory power than the regionally representative reconstruction, but the Chuska reconstruction effectively captures snowpack extremes and snow drought timing unique to the Chuska Mountains, and may hold greater relevance to Navajo water management.

Practical Implications

Snowpack in the Chuska Mountains is a valuable source of water on the Navajo Nation that is threatened by drought and climate change. Navajo water managers work intensively to monitor and maintain this important water source. Snowpack monitoring in the Chuska Mountains began in 1985. Despite the importance of these continual data, Chuska snow records are comparatively short. The short-length records make contextualizing current climatic relationships between snow and water resources in this drought-prone place extremely difficult. Without consistent, long-term climate information related to snowpack, Navajo water managers face significant challenges with anticipating impacts from climate variability. Informal conversations with Navajo water managers about recent snowpack declines and earlier seasonal runoff provide accounts of the economic and cultural consequences of these declines. At the same time, Navajo water managers are searching for quantitative documentation of historical changes in snowpack that supplements, informs, corroborates, and supports existing tribal knowledge, and can in turn help to guide decision-making among local resource managers.

The Navajo Nation Water Management Branch (NWMB) initiated this collaborative research. The research employed an ongoing, interactive approach to climate information production that was guided by the Navajo Nation and driven by their management needs. This deliberate approach was intended to inform Navajo planning for water sustainability in times of drought and in the face of projected warming. The relationships developed through

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this process were critical to ensure that snowpack reconstructions were relevant and useful. These relationships also lay a foundation for future endeavors that forge integrated science-water management partnerships with tribal governments.

Tree-ring based climate reconstructions require two main components, i) a climate record that is long enough for robust reconstruction model calibration, and ii) tree-ring chronologies that exhibit a statistical relationship to the variability in the climate data. Intuitively, Chuska Mountain snow records (1985–2015) should be the dataset used to calibrate a Chuska Mountain snowpack reconstruction model. But, short Chuska Mountain snow records raised questions about the scientific robustness of a reconstruction generated using such limited data. For this reason, we developed two tree-ring based snow water equivalent (SWE) reconstructions. One reconstruction is calibrated on the SWE record from the Chuska Mountains. The second reconstruction is calibrated on a longer SWE record, Williams Ski Run (1967–2015), from the San Francisco Peaks approximately 250 km to the southwest. The Williams Ski Run SWE data are representative of SWE conditions in the northern Arizona region, which includes the Chuska Mountains. We then compare the resulting reconstructions in terms of reconstruction skill and model validation, and the ability of the snowpack estimates to replicate observed snowpack data characteristics. The reconstruction calibrated on the Chuska snow record better matched the details of snowpack variability in the instrumental record, but generally failed to capture the magnitude of extremes. The Williams Ski Run reconstruction captured a broader range of regional snowpack variability, but it missed local low-snowpack intervals specific to the Chuska Mountains. Knowing these trade-offs allows Navajo water managers to determine what climate information contained within the reconstruction is most useful for their immediate decision-making.

The research reflects on the usefulness of climate information given that use inspired science is complex, time-intensive, and must enable knowledge production that is beneficial to, and reflects the concerns and needs of, the information user. What makes this kind of research difficult is that the value attributed to research relevance can be different for the researcher versus the user of the information. Further, the research must be believable, trusted, and readily usable by Navajo water managers in order to adequately meet their needs. We found that this dual-pronged approach of i) Navajo directed research objectives, and ii) comparisons of climate services products according to scale begins to address the gap in climate information on the Navajo Nation while also producing information that specifically addresses locally relevant questions.

1. Introduction

Gaps in actionable climate information for water management decision making often arise from spatially sparse hydroclimatic data and short-duration climatic records. These factors have historically limited assessments of climate vulnerability by resource managers on the Navajo Nation in the southwestern U.S. (Novak, 2007; Ferguson et al., 2011; Redsteer et al., 2013; Tsinnajinnie et al., 2018; Tulley-Cordova et al., 2018). There is a need for customized climate information on the Navajo Nation that integrates Western science and indigenous knowledge in ways that are beneficial to both knowledge systems (Redsteer et al., 2010; Chief et al., 2016), that can be readily used in climate-related decision making (Yazzie and Kim, 2019), and that ensure that relevant and trusted climate information is the outcome of a process that considers the concerns and perspectives of the user of the information (Clark et al., 2002; Cash and Buizer, 2005; McNie, 2013).

Climate services is emerging as a functional framework that capitalizes on diverse expertise (Brasseur and Gallardo, 2016), recent scientific advances, and the co-production of knowledge (Bremer et al., 2019) to produce user-relevant climate products to support decision-making at various scales (e.g. Cortakar et al. 2016). Definitions of climate services incorporate key components of climate knowledge production including the timely availability and customization of climate information, efficient transfer and translation of that information, and guidance or counseling on using the information to support climate change adaptation, mitigation, and risk management (Brasseur and Gallardo, 2016). According to Brasseur and Gallardo (2016) lacking or insufficient climate services components, including the lack of user-relevant products offered by the scientific community, present challenges to the successful application of climate services. In this study, we focus on improving one component of climate services, the development of relevant and usable climate information at the local scale (heretofore referred to as climate information). Research demonstrates that collaborative development of climate information is more likely to result in useful science (Jasanoff and Wynne, 1998; Jasanoff, 2004; Lemos and Morehouse, 2005; van Kerkhoff and Lebel, 2015). Useful climate information is therefore most likely achieved when decision makers define the problem and the desired climate product (Clark, 2002), and when the users of the information participate in its production (Lemos and Morehouse, 2005; Tall and Njinga, 2013; Lemos et al., 2014; Wall et al., 2017).

The Navajo Nation has been in a state of drought emergency since 2002 when the Navajo Nation Commissioners on Emergency Management issued the first Navajo Nation Drought Emergency Declaration. Severe drought has affected the area since about 1999 (Redsteer et al., 2011; Crimmins et al., 2013) and has been exacerbated by desertification from poor livestock management, over population of ferel horses, and overgrazing. The drought is negatively affecting crops, food supplies, water storage, economic conditions and ecosystem services (Ferguson et al., 2016; EL-Vilaly et al., 2018), and is often raised by tribal members and especially elders as an unusually long-lasting problem (Ferguson et al., 2011; Redsteer et al., 2011). Local observational climate data to address concerns over the recent drought are either lacking or too short to estimate long-term changes in trend or variability. For example, assessments of snowpack and snow water equivalent (SWE) measurements in the Chuska Mountains of the Navajo Nation have been ongoing since the 1980s, but this time period has been insufficient to reveal a discernable trend due to drought or climate change (Tsinnajinnie et al., 2018). The lack of trend in SWE is inconsistent with observations of declining surface waters and streamflow across the Navajo Nation (Redsteer et al., 2011) and with reports of drying snow-fed lakes in the Chuska Mountains. These reductions in surface waters are likely connected to SWE and its variability; however it is difficult to distinguish the role of precipitation versus temperature in snowpack decline with short instrumental records, prompting the need for long-term data on accumulated cool-season snowpack (or SWE) in the Chuska Mountains.

Driven by the need to plan for and adapt to climate change, water managers of the Navajo Nation invited us to help in understanding local variability in climate and water resources. They identified the amount and variability of snowpack in the Chuska Mountains as a key concern. The Navajo Nation encompasses over 70,000 km^2 in the Four Corners region of the American Southwest (Fig. 1). Much of the reservation is high-desert grassland, typical of the Colorado Plateau, but on the eastern part of the reservation the Chuska Mountains reach nearly 3,000 m elevation with a winter precipitation regime that is dominated by snow. The Chuska Mountains provide most local surface water to the eastern portion of the Navajo Nation (Harshbarger and Repenning, 1954; Wright, 1964; Garfin et al., 2007) and are the headwaters for several perennial creeks that feed multiple reservoirs and river systems, such as the Little Colorado River, the San Juan River, and in Canyon de Chelly. Navajo community members on the eastern reservation are strongly reliant on snow-fed surface water for livestock, fishing, and agriculture (Crimmins et al., 2013; Wright, 1964), diverting water resources to feed small-scale irrigation structures to support traditional farming communities (Harshbarger and Repenning, 1954). These systems may be

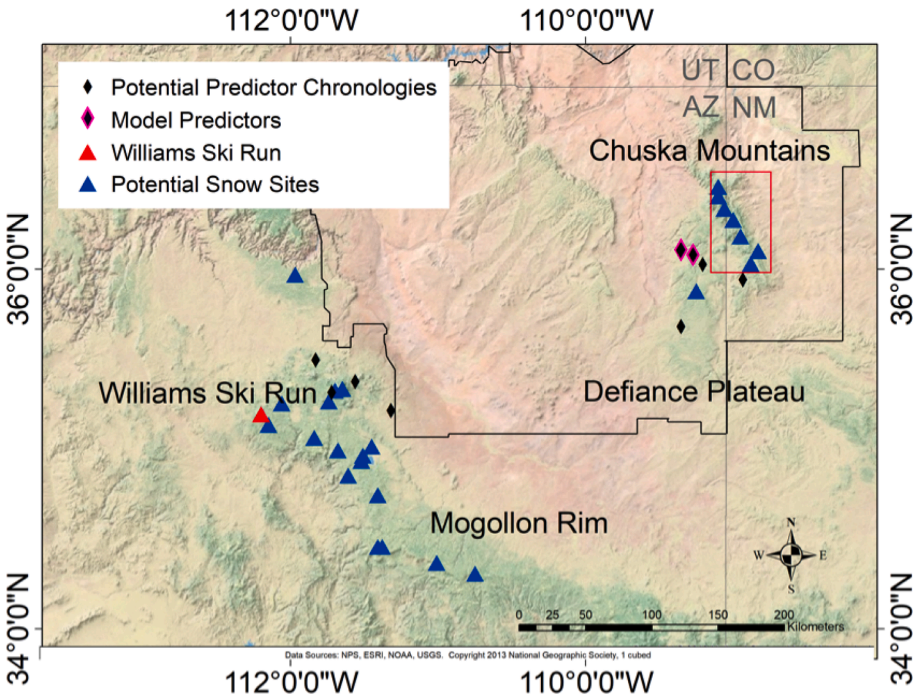

Fig. 1. The Navajo region of northeastern Arizona and northwestern New Mexico. The Navajo Nation boundary is in black. The Four Corners (the intersection of the four states Colorado, Utah, Arizona and New Mexico) is in the upper right portion of the map. The location of all potential snow sites evaluated for calibration (see text) and the tree-ring sites used in this study are shown, blue triangles and black diamonds, respectively. (Spider Rock chronologies overlap at the map scale.) Model predictors are indicated as pink diamond outlines. The Williams Ski Run (WSR) model predictand is indicated with the red triangle. Snow sites used for the Chuska Mountains SWE predictand (CHU) are within the red box. Map image is the intellectual property of Esri and is used herein under license. Copyright ©2013 National Geographic Society, i-cubed. All rights reserved.

threatened by increased temperature and projected shifts in cool-season precipitation toward sporadic snow accumulation and earlier spring melt (Mote, 2006; Li et al., 2017).

To better understand fluctuations in snowpack over time, we utilize tree rings to reconstruct snowpack for the Navajo Nation. The hydrological and biological basis for using tree rings is that the growth of southwestern U.S. montane conifers living on well-drained, south-facing slopes is controlled by winter precipitation (Fritts, 1976; Woodhouse, 2003; Touchan et al., 2010; Pederson et al., 2011; Faulstich et al., 2013). Moisture, which arrives in winter in these locations, controls tree growth in the subsequent growing season through snowmelt entering the root zone in late spring and early summer (George et al., 2014). Therefore, conifer tree rings provide proxy records of interanaul variability of seasonal moisture.

The goal of this study was to work in partnership with the NWMB to place local snowpack data into a centuries-long context using tree rings, producing relevant and useful climate information for management. In our preliminary work, we found that a SWE reconstruction based solely on Chuska Mountain data fell short of our expectations for generating a robust statistical model (e.g. the length of the calibration dataset is only 30 years in length). We also aimed to capture as much natural variability as possible from the calibration dataset. In the southwestern United States, where precipitation variability is high, short calibration datasets are likely to miss important extremes. Therefore, we generated a second reconstruction from regionally available data that better met standards for skillful reconstructions, but that may have traded its local usefulness in the process. Here, we evaluate the relevance and usefulness of these two reconstructions in terms of 1) the statistical robustness (reconstruction skill and validation), and 2) the replication of observed snowpack characteristics most meaningful to the NWMB. We further use the multi-century reconstructions to assess the magnitude and duration of low snowpack periods in the 20th and 21st centuries in a longer-term context.

2. Materials and methods

2.1. Data

2.1.1. Snowpack datasets

The NWMB provided us with SWE data for the Chuska Mountains. The data were manually collected from snow course sites near the first and middle of each month from January 1st through April 1st using a snow coring tube and following standard Natural Resources Conservation Service (NRCS) procedures. Snow density was calculated from the mass and volume of snow in the tube. To obtain SWE estimates from the snowpack, snow density calculations were multiplied by snowpack depth. From these data, eight March 1 SWE site records – the annual SWE measured on March 1 generally representative of annual maximum SWE – were derived spanning 1985–2015 (Fig. 2). Some higher elevation Chuska sites had slightly higher SWE averages on March 15, but the comparison record at Williams Ski Run was only collected on March 1. Because average values for March 1 and March 15 in the Chuskas were very similar, we used March 1 to maintain consistency with the comparison record. The eight Chuska Mountains snow sites were then averaged, which we henceforth refer to as the "Chuska" series. Initial assessment of the eight Chuska March SWE records revealed low coherence between them in the early years (1985–1990), making it difficult to justify using the entire record as a basis for statistical calibration of the reconstruction model. To shorten the record would result in a calibration dataset that does not meet or exceed 30 years, which is an historical rule of thumb for statistical analysis of climate (Guttman, 1989). However, longer calibration datasets allow the reconstruction model to capture a larger range of natural variability, especially extreme values. To accommodate this shortcoming, we capitalized on a finding that snowpack in the San Francisco Peaks and Mogollon Rim of northern Arizona is closely linked to the Chuska Mountains (250 km distant) via winter storm tracks (Tsinnajinnie, 2011). Therefore, we obtained 26 SNOTEL and snow course site records from northern Arizona as a second set for a potential March SWE calibration (USDA Natural Resources Conservation Service, 2020). Of these 26 sites, we excluded those with < 30 years of continuous recording, leaving a suite of 17 snow course sites to compare with the Chuska record. Correlations of March 1 SWE from

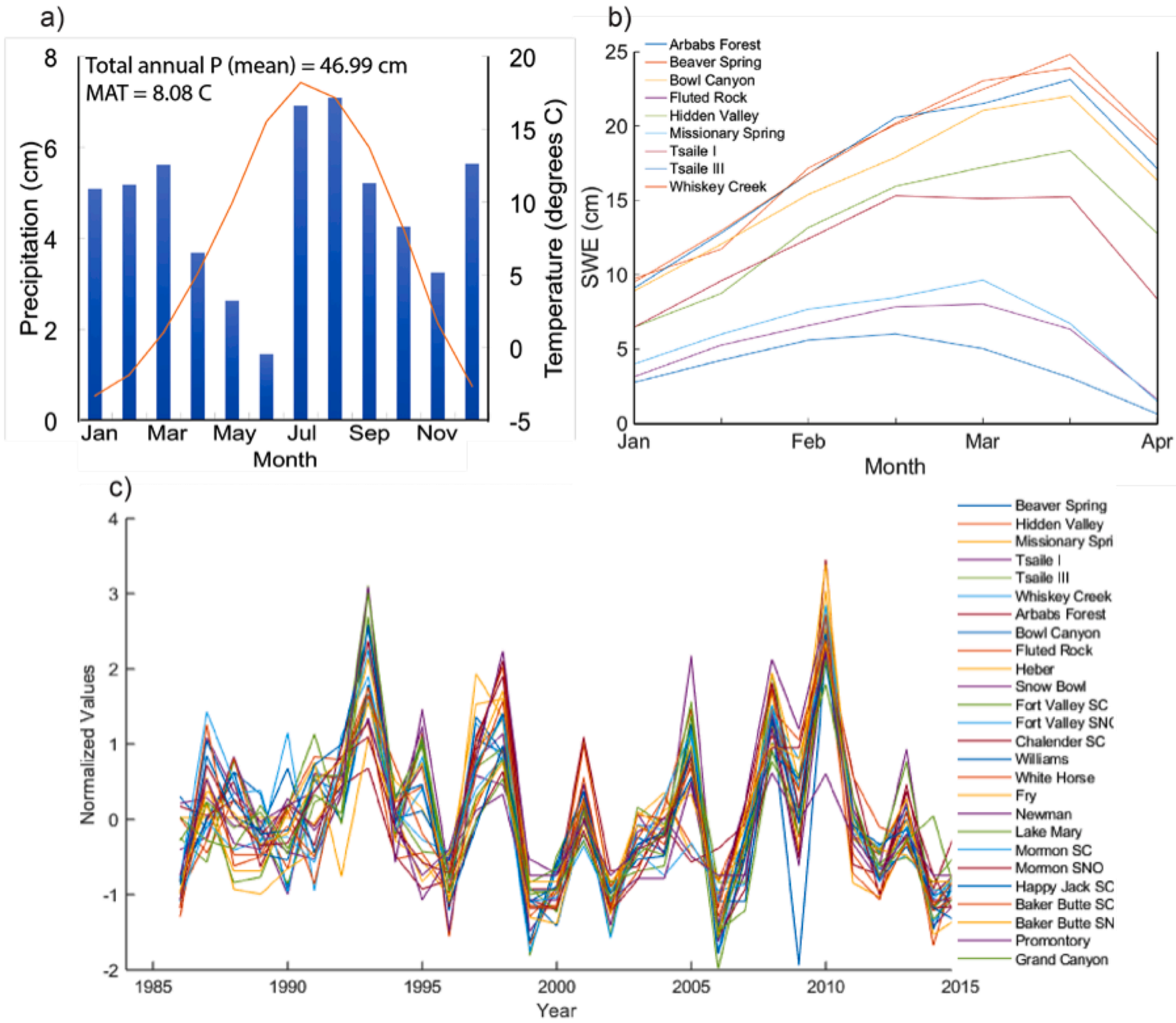

Fig. 2. a) Climograph for the Navajo region using PRISM data (1895–2015; PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu, created 20 May 2018). Mean annual precipitation (cm) and mean annual temperature (MAT; °C) indicated in the top left of the panel. b) Chuska mountain SNOTEL snow course sites average monthly SWE (1985–2015). c) March SWE from SNOTEL and snow course measurement stations in the Chuska Mountains, San Francisco Peaks, and Mogollon Rim, Arizona (common period 1986–2015).

the 17 northern Arizona SWE sites with the Chuska series ranged from $r = +0.67$ (Chandler) to $r = +0.86$ (Happy Jack). Williams Ski Run snow course (WSR; 1967–2015) was longer than our discretionary 30-year threshold, the record contained few zeros or missing values, and had a strong average correlation with the Chuska series ($r = +0.83$). Averaged Chuska Mountains March 1 SWE (CHU; $n = 30$) and Williams Ski Run March 1 SWE (WSR; $n = 48$) were then used for subsequent reconstructions of Chuska Mountain and regionally representative snowpack, respectively.

2.1.2. Tree-ring datasets

The forests of the Chuska Mountains are dominated by ponderosa pine (*Pinus ponderosa*) above 2,300 m, with dry mixed-conifer forests including a large proportion of Douglas-fir (*Pseudotsuga menziesii*) occurring at higher elevations and in cold-air drainages. Lower-elevations are predominantly pinyon-juniper (*Pinus edulis-Juniperus* spp.) communities (e.g. Cole et al., 2013; Guiterman et al., 2019; Hartsell et al., 2020). There is a dense network of tree-ring sites in the Four Corners area that includes pinyon, ponderosa pine, and Douglas-fir chronologies (George et al., 2014), many of which are available on the ITRDB.[1] We screened the available sites and selected four tree-ring chronologies from the Navajo Nation and Mogollon Rim/San Francisco Peaks area that had significant correlations ($p < 0.01$) with Chuska SWE and maximum overlap with the calibration. Most of the sites had previous collections (e.g. Dean and Funkhouser, 1995; Sheppard et al., 2005) that we updated with collections between 2015 and 2017. Six new site collections were made for Guiterman (2016) and we use them in this study. The 10 sites range in elevation from 1,828 m to 2,714 m (Table 1).

Tree-ring samples for the updated chronologies were collected, mounted, sanded, visually crossdated, and measured for total ring width using standard methods of dendrochronology (Speer, 2010). We checked for accuracy in crossdating and performed quality control of the measurement data iteratively using the software program COFECHA (Holmes, 1983). Where available, we combined the ring-width series from the original collections with our updated ring-width series. We standardized the ring widths in R using the *dplR* library (Bunn, 2008; R

[1] ITRDB data available at the International Tree-Ring Data Bank, ITRDB; https://www.ncdc.noaa.gov/paleo/treering.html.

Table 1
Tree-ring site chronologies used in the predictor pool. Species (ssp.) codes are *Pseudotsuga menziesii* (PSME), *Pinus ponderosa* (PIPO), and *Pinus edulis* (PIED). The first and last year for each chronology are listed as Recon. Statistics are described in the text. *Includes original plus updated collections.

Site Code	Site Name	Ssp. Code	Recon	No. Cores*	No. Trees*	Elev. (m)	Collection Date(m-y)	Update Collectors	Publication
SPU	San Fran. Peaks Update	PSME	1763–2016	46	24	2036	Jan-17	Brice; Sheppard; Arizpe	Salzer and Kipfmueller (2005). Reconstructed temperature and precipitation on a millennial timescale from tree-rings in the southern Colorado Plateau, USA. Climatic Change, 70(3), 465–487.
SMU	Slate Mtn. Update	PIPO	1590–2016	60	31	2714	Jan-17	Brice; Sheppard; Arizpe	Meko, D. M., and Hirschboeck, K. K. (2008). The Current Drought In Context: A Tree-Ring Based Evaluation of Water Supply Variability for the Salt-Verde River Basin Final Report. Salt River Project, Tucson, Ariz.
RMU	Robinson Mtn. Update	PIPO	1621–2016	46	24	2130	Jan-17	Brice; Sheppard; Arizpe	Meko, D. M., and Hirschboeck, K. K. (2008). The Current Drought In Context: A Tree-Ring Based Evaluation of Water Supply Variability for the Salt-Verde River Basin Final Report. Salt River Project, Tucson, Ariz.
SCU	Sunset Crater Update	PIPO	1837–2015	25	17	2127	Jan-17	Brice; Sheppard; Arizpe	Sheppard, P. R., May, E. M., Ort, M. H., Anderson, K. C., and Elson, M. D. (2005). Dendrochronological responses to the 24 October 1992 tornado at Sunset Crater, northern Arizona. Canadian Journal of Forest Research, 35(12), 2911–2919.
OCW	Oak Creek Wash	PSME	1200–2015	29	19	2325	Jan-17	Guiterman	Guiterman, C. H. 2016. Climate and human drivers of forest vulnerability in the US Southwest: Perspectives from dendroecology. PhD Thesis. University of Arizona.
SRD	Spider Rock Doug. Fir	PSME	1636–2014	12	6	1980	Jun-16	Guiterman	Guiterman, C. H. 2016. Climate and human drivers of forest vulnerability in the US Southwest: Perspectives from dendroecology. PhD Thesis. University of Arizona.
STC	Small Twin Canyon	PIPO	1656–2014	10	10	2152	Jun-16	Guiterman	This study
SRO	Spider Rock Overlook	PIED	1601–2015	62	32	2134	Jun-16	Guiterman	Guiterman, C. H. 2016. Climate and human drivers of forest vulnerability in the US Southwest: Perspectives from dendroecology. PhD Thesis. University of Arizona.
SSR	South of Spider Rock	PSME	1396–2014	10	10	1980	Jun-16	Guiterman	Guiterman, C. H. 2016. Climate and human drivers of forest vulnerability in the US Southwest: Perspectives from dendroecology. PhD Thesis. University of Arizona.
DCC	Defiance Cross Canyon	PIPO	1340–2015	52	21	2159	Jun-16	Guiterman	Guiterman, C. H. 2016. Climate and human drivers of forest vulnerability in the US Southwest: Perspectives from dendroecology. PhD Thesis. University of Arizona.

Core Team, 2019), employing either a modified negative exponential curve or cubic smoothing spline with a frequency response of 50% at a wavelength of two-thirds the length of the series (Cook and Kairiukstis, 1990). Standard chronology statistics were calculated in *dplR*. Each site includes 6–32 trees with chronology statistics that show relatively strong relationships between trees at the site level ($r > 0.48$). All sites show an expressed population signal (EPS) over 0.85, the threshold commonly accepted for adequate sample size for climate reconstruction (Wigley et al., 1984; Briffa and Jones, 1990).

2.2. Reconstruction development and analysis methods

2.2.1. Snowpack reconstruction and skill metrics

In preparation for the regression analysis used to reconstruct March SWE, the statistical relationship between the tree rings and the snowpack was evaluated. We used correlation coefficients (r) to test the strength and significance of the relationship between each chronology in the tree-ring network and the snowpack data. The 10 chronologies were significantly correlated ($p < 0.05$) with the SWE time series and these were retained in a pool of potential reconstruction model predictors. Normal distribution of the regression variables was verified and met the statistical assumption of no significant trend or autocorrelation in the March SWE data.

Stepwise multiple linear (least-squares) regression was used to calibrate each reconstruction model on March SWE data (Criteria: Probability-of-F-to-enter $< = 0.05$, Probability-of-F-to-remove $> = 0.10$). The R^2 statistic provides a measure of the explanatory power of the model and the F-ratio estimates the statistical significance of the regression equation. The Durbin-Watson (D-W) statistic assesses serial correlation in the model residuals. A D-W statistic at or near 2 indicates zero first order autocorrleation in the regression residuals. The Standard Error of the Estimate (SEE) statistic indicates uncertainty of the predicted values during the calibration period. Leave-one-out cross validation was used to check the reconstruction model performance compared to March SWE observations (Michaelsen, 1987). The leave-one-out process withholds one data point from the calibration period and a prediction is made for that point. This process proceeds iteratively for each value in the calibration period. The validation statistics Reduction of Error (RE) and Root Mean Square Error of the validation (RMSEv) verify the skill of the reconstruction based on the leave-one-out series (Fritts, 1976; Cook et al., 1999). The RE statistic compares the mean square error of the reconstruction to the mean square error of the calibration data average. The RE result indicates if the reconstruction provides more information from the estimates over the validation period than the calibration data mean would provide, and in a skillful model the RE will be nearly equivalent to the R^2. The range of the RE statistic is zero to $+1$, with a higher positive value indicating skill in the model (a value of $+1$ meaning perfect skill) (Fritts, 1976).

2.2.2. Runs analysis

We conducted runs analysis to identify multi-year periods of low and of high snowpack in the Chuska Mountains. Following Faulstich et al. (2013), we classified runs periods based upon a threshold of at least two consecutive years above/below the reconstruction mean. Because a single year of above average snowpack may not provide sufficient moisture for the region to recover from several years of below average snowpack (Crimmins et al., 2013), we allowed the consecutive years to be interrupted by no more than one consecutive March SWE year of opposite sign. When defining high snowpack runs, it makes sense to use the same criteria because increased cool-season precipitation is likely to improve wet soil conditions and recharge of local water resources despite a single year below average (Redsteer et al., 2010; Crimmins et al., 2017). Assessing drought in the Southwest is sensitive to decisions of runs thresholds (Meko et al., 1995). For example, without our exception rule allowing one season of opposite sign in a run, the 1950s drought (1950–1964 in the Williams Ski Run results) would be two separate dry periods (1950–1951, 1953–1964), thus minimizing the duration and magnitude of the drought in our interpretation of results and possibly underestimating the impacts of the dry period. Duration (number of consecutive years broken by no more than one year of the opposite sign), magnitude (cumulative deficit or surplus), and intensity (magnitude divided by duration) for each drought or pluvial event were ranked using the method described in Faulstich et al. (2013). After assigning a rank for each measure, the ranks were summed for a total score. The total scores per event were then ranked to establish the most extreme drought and pluvial periods.

2.2.3. Decadal-scale variability, ranked average deficits, and extreme years

To better understand decadal-scale variability in the reconstruction, a 20-year cubic smoothing spline was calculated and overlaid on the annual March SWE reconstructed series. The spline was used to identify periods when the smoothed series remain above or below the long-term mean and to assess the distribution through time of prolonged above or below average snowpack. The unsmoothed reconstruction and the smoothed reconstruction were converted to a departure series by subtracting the long-term reconstruction mean. The departure series values were ranked to examine extreme drought years and decadal periods. The ten driest individual departure years were evaluated in terms of largest deficit in a single year in the reconstruction. The five lowest non-overlapping 20-year periods in the smoothed series were centered on lowest value in the smoothed series and averaged over the period for which values were negative.

3. Results

3.1. Evaluation of the calibration datasets

The calibration datasets revealed important differences between Chuska (CHU) and Williams Ski Run (WSR) observations. The CHU March SWE mean is 18.69 cm, with a standard deviation and variance of 8.32 and 69.19, respectively (Table 3). The WSR March SWE mean is 21.33 cm, with standard deviation and variance of 12.86 and 165.53, respectively. Series ranks for CHU and WSR show that 2006 was the driest year in the instrumental record for each of the two SWE locations. The ranks of the remaining four years are not the same between the two series. The years 2015 and 1996 are both ranked top five; however 2015 was third (CHU) and second (WSR), and 1996 was fourth (CHU) and fifth (WSR). The extremely dry year across the southwestern U.S. 2002, ranked third driest in the WSR record but it did not rank top five in the CHU record. After standardization, the overall intensity of the 2000s drought (1997–2007) in CHU was −0.250 cm and the overall intensity of the same drought in WSR was −0.527 cm. The WSR running total (magnitude) for the 2000s drought was 47% drier than the CHU magnitude. The percent of average over these years was 88% of average in CHU and 64% of average in WSR.

Table 3
Instrumental (Chuska (CHU) = 1985–2015; Williams Ski Run (WSR) = 1967–2014) and reconstruction (Recon) snow water equivalent (cm) statistics during each calibration (cal) period, and for the full reconstructions (CHU = 1656–2014; WSR = 1694–2014).

	N	Mean	Min	Max	Range	Std. Dev.
CHU Observed	30	18.69	0.91	38.24	37.33	8.32
CHU Recon (cal period)	30	18.69	10.26	29.51	19.25	5.31
CHU Recon	359	19.00	10.26	32.10	21.84	4.68
WSR Observed	48	21.33	0.00	49.78	49.78	12.86
WSR Recon (cal period)	48	21.33	−2.67	37.87	37.87	8.70
WSR Recon	359	21.97	−2.67	46.32	46.32	9.32

3.2. Chuska local snowpack reconstruction

Stepwise regression identified one tree-ring chronology collected in the Chuska Mountains from *P. ponderosa* at Small Twin Canyon (STC) as a predictor for Chuska Mountains March SWE (CHU). The final reconstruction model is:

$$CHU = 4.035 + 0.534(STC) \quad (1)$$

The CHU model explains 41% of the variance in Chuska March SWE in the 30-year calibration period (1985–2014, Table 2). The F-ratio indicates that the regression equation is statistically significant. The RE (0.41) and RMSEv (6.198) values are comparable to their respective calibration statistics, $R^2 = 0.41$ and SEE = 6.523, showing that this model has skill in estimating Chuska SWE during cross-validation (Table 2, Fig. 3). The sign test demonstrates that the direction of observed and estimated departures from the instrumental mean agree more often than would be expected by chance alone. Analysis of reconstruction residuals revealed no violation of regression assumptions. Reconstruction residuals are normally distributed, show no significant trend or changes in variance with time, and no significant autocorrelation. Reconstructions tend to underestimate extreme years, and this is demonstrated in the years where observation values are higher or lower than reconstructed values. However, this reconstruction replicates some extreme values found in the calibration series (i.e. 1988, 1990, 1995, 1996, 2002, 2006). The full reconstruction spans from 1656 to 2014.

3.3. Williams Ski Run snowpack reconstruction

Stepwise regression identified two tree-ring chronologies collected in the Chuska Mountains from *P. ponderosa* and *P. menziesii* at Small Twin Canyon (STC) and South of Spider Rock (SSR) as the best predictors of Williams Ski Run March SWE (WSR). The final reconstruction model is:

$$WSR = -3.113 + 0.363(STC) + 0.381(SSR) \quad (2)$$

The model explains 47% of the variance in Williams Ski Run SWE in the 41-year calibration period (1967–2014, Table 2). The F-ratio

Table 2
Stepwise regression model results for the two March SWE reconstruc-tions, top) Chuska Mountains (CHU) and bottom) Williams Ski Run (WSR). *H0: Zero first order autocorrelation in residuals. Accept; prob level 0.01. **Significant at p<0.05. ***Leave-one-out (LOO) cross validation description in the text.

CHU Reconstruction					
Reconstruction	R^2	R^2_{adj}	SEE	Durbin-Watson	F-ratio
	0.41	0.39	6.523	1.742*	19.18**
LOO Validation***		RE	RMSE	Sign Test (hit/miss)	
		0.41	6.198	25/4**, N = 29	
WSR Reconstruction					
Reconstruction	R^2	R^2_{adj}	SEE	Durbin-Watson	F-ratio
	0.47	0.45	9.548	2.051*	20.17**
LOO Validation***		RE	RMSE	Sign Test (hit/miss)	
		0.40	9.870	34/13**, N = 46	

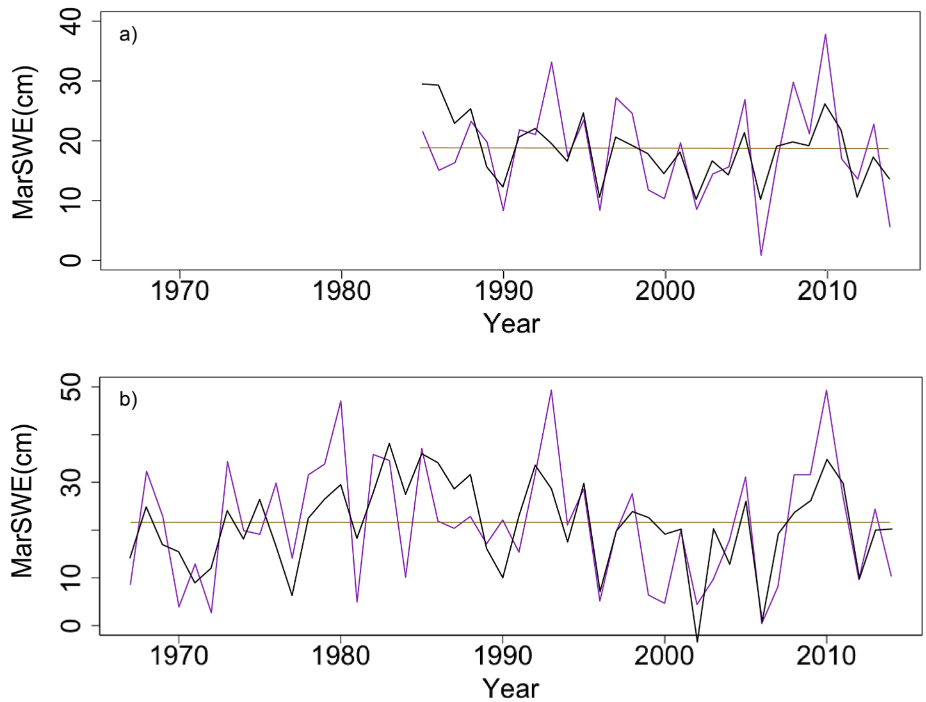

Fig. 3. Observed (purple) and predicted (black) March SWE and calibration mean (brown) at a) CHU Chuska mountain local snow for the years 1985–2014 and b) WSR Williams Ski Run for the years 1967–2014. MarSWE is generally representative of the annual maximum SWE value.

indicates that the regression equation is statistically significant. The RE (0.40) and RMSEv (9.870) values are comparable to their respective calibration statistic, $R^2 = 0.47$ and SEE = 9.548, showing that this model skillfully estimates WSR SWE during cross-validation (Table 2, Fig. 3). Near-zero measured ring-widths can produce unrealistic negative estimates in the reconstruction model (e.g. the year 2002). However, the 95% confidence intervals (C.I.) of the error associated with the model include values in the positive range (e.g. the 95% C.I. range for 2002 is −12.541 cm to 7.199 cm). As with the CHU model, tests show no violation of regression assumptions. Sign test results demonstrate significant agreement between the WSR calibration series and the reconstruction during the calibration period. The WSR model best captures below-average observed values in the second half of the calibration period, rather than above average observed values in the same interval. The length of the reconstruction is limited by the shortest chronology that contributes to it. Cutoff years for robust chronologies to be used in the reconstruction are 1694 (STC) and 1654 (SSR). The STC chronology (1656–2014) reached an EPS value of 0.85 at 1694, and thus the full reconstruction spans from 1694 to 2014.

3.4. Analysis of the reconstructions

The smoothed reconstructions reveal that the duration of multi-year periods of low and high SWE varies similarly in both reconstructions across the three centuries (Fig. 4). In the early-to-mid 1700s, periods of low snowpack occurred between long intervals of above-average snow.

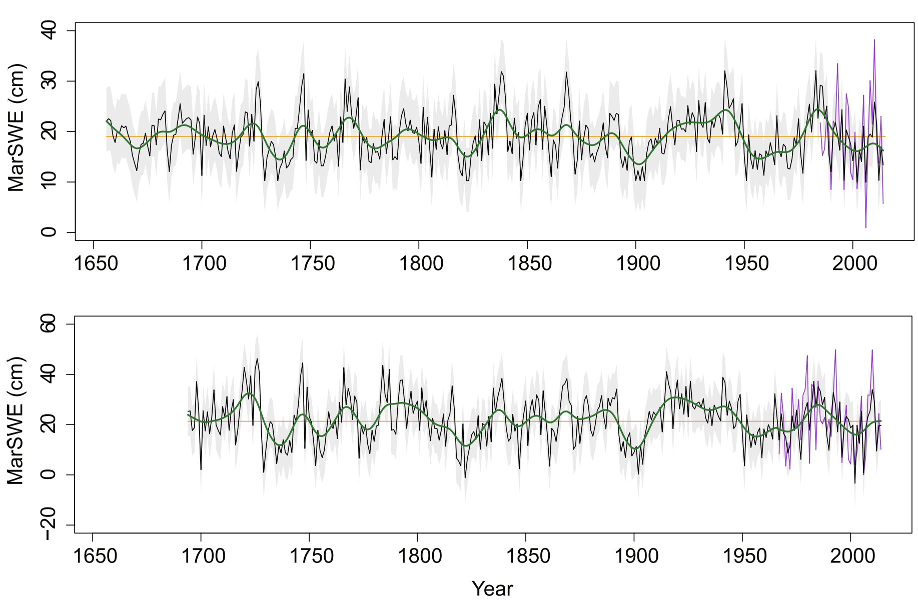

Fig. 4. MarSWE reconstructions (black) with the 95% confidence interval in grey shading for a) CHU SWE (1656–2014 AD) and b) WSR SWE (1694–2014 AD). The purple line is the calibration series. The long-term mean is the brown line. The green line is the 20-year cubic smoothing spline which reflects multi-year periods of above average conditions. When it is above the mean it reflects multi-year periods of above average conditions and when it is below the mean it reflects below average conditions.

The first half of the 19th century is dominated by a long-duration below-average snowpack covering the 1820s. In the second half of the 19th century, low snowpack periods were of shorter duration frequently interrupted by similar length or longer wet intervals. The 20th century has less frequent and long dry or wet periods.

Runs analysis highlights the duration of persistent snowpack conditions and reveals periods of extremely high and low snowpack (Table 4). The duration of high snowpack periods from the CHU reconstruction in the top five high snowpack intervals ranges between 11 and 18 years. The highest ranked run of high snowpack occurred in 1915–1932 (18 years). This period also fell within the longest run of high snowpack in the WSR reconstruction (39 years). Of the four highest ranked high CHU snowpack periods, three occur in the 1900s. Low CHU snowpack in the top 5 runs periods ranges between 8 and 28 years, whereas the top 5 low snowpack periods in the WSR reconstruction range from 8 to 17 years in duration. The extended low CHU snowpack period (1950–1977, 28 years) is the longest. The most recent drought (1999–2006) ranks number six among the ten lowest snowpack periods in the CHU reconstruction. In the WSR reconstruction, the duration of the top five high snowpack periods ranges between 5 and 39 years. The highest ranked period of high snowpack occurred in 1718–1727 (10 years). The longest run of high WSR snowpack occurred in 1907–1945 (39 years). Of the four highest ranked high snowpack years, three periods occur in the 1700s. The extended low WSR snowpack period (1818–1834, 17 years) is the longest, and ranked most severe. The low snowpack period (1950–1964, 15 years) is also present in the WSR reconstruction runs, ranked number 4 in severity in the ten ranked periods. The most recent drought (2000–2007) ranks fifth among the ten lowest snowpack periods in the WSR reconstruction.

Extremely dry single years often occur during longer deficit periods (Fig. 5). The single driest year in the CHU reconstruction is 1729 and falls within a longer deficit ranking in the top five deficit periods in the reconstruction. The single driest year in the WSR reconstruction is 2002. Other top ten dry years such as 1822, 1900–1904, 1951, and 2006 (CHU only) coincide with extended, severe average deficits (based on the 20-year spline) in the early 1800s, the early 1900s, and the mid-20th century. Other dry years in the WSR reconstruction, such as 1700, 1847, 1861, 2002, and 2006 are not part of a longer deficit in consecutive years relative to other periods in the long-term record. The year 1847 is the single individual year in the CHU reconstruction that is not within a longer deficit period.

4. Discussion

This study aimed to produce the most relevant and useful information about multi-century snowpack variability in the Chuska Mountains for the Water Management Branch of the Navajo Nation. In so doing, we assess the trade-offs between the use of a relatively short, but locally-relevant snowpack instrumental record versus a longer, but potentially less locally-relevant instrumental record in developing a tree-ring based reconstruction of snowpack variability. In a comparison of the two observed snowpack records and reconstructions, we i) assess the statistical characteristics and extremes of the instrumental data, ii) evaluate the ability of each reconstruction to reflect means and extremes in the instrumental data, and iii) compare the ability of the reconstructions to capture known drought episodes. To assess the reconstructions as usable and relevant climate information, we evaluate the SWE reconstruction implications for local water resources and the collaborative development of climate information.

4.1. Evaluating the instrumental records for March SWE

Our findings show similarities and differences in the observed SWE between the Chuska Mountains (CHU) and the Williams Ski Run (WSR). Though the 30-year averages between datasets are similar, and the datasets are highly correlated, the strong correlation arises from synchrony in sign, not the magnitude of above-average or below-average snowpack, which is generally larger at WSR, especially in extreme years. The only exception is 2006, for which both datasets showed near-zero March SWE. The 2006 winter had the lowest snowpack in the 1985–2015 record at both sites.

The extreme 2000s drought (1997–2007) further highlights the

Table 4
Runs analysis for low snowpack (left) and high snowpack (right) periods in the CHU (top) and WSR (bottom) reconstructions.

CHU Runs Analysis

Ranked Low Snowpack	Low Snowpack Period	Period Duration	Magnitude (running total/period)	Intensity (magnitude/duration)	Ranked High Snowpack	High Snowpack Period	Period Duration	Magnitude (running total/period)	Intensity (magnitude/duration)
1	1729–1742	15	−27.059	−1.804	1	1915–1932	18	155.276	8.626
2	1894–1914	22	−32.241	−1.465	2	1979–1988	11	107.893	9.808
3	1950–1977	28	−37.922	−1.354	3	1826–1840	15	133.521	8.901
4	1818–1829	12	−19.419	−1.618	4	1935–1945	11	105.977	9.634
5	1841–1848	8	−6.392	−0.799	5	1759–1774	16	134.387	8.399
6	1999–2006	8	−11.212	−1.402	6	1719–1727	9	82.486	9.165
7	1707–1713	7	−5.151	−0.736	7	1849–1859	11	93.878	8.534
8	1667–1676	10	−10.979	−1.098	8	1687–1695	9	78.017	8.669
9	1879–1887	9	−8.462	−0.940	9	1743–1751	9	80.453	8.939
10	1752–1758	7	−10.866	−1.552	10	1656–1666	11	88.921	8.084

WSR Runs Analysis

Ranked Low Snowpack	Low Snowpack Period	Period Duration	Magnitude (running total/period)	Intensity (magnitude/duration)	Ranked High Snowpack	High Snowpack Period	Period Duration	Magnitude (running total/period)	Intensity (magnitude/duration)
1	1818–1834	17	−59.921	−3.525	1	1718–1727	10	54.347	5.435
2	1728–1744	17	−59.908	−3.524	2	1978–1988	11	30.759	2.796
3	1893–1908	15	−58.176	−3.878	3	1791–1804	14	36.300	2.593
4	1950–1964	15	−40.028	−2.669	4	1783–1787	5	26.795	5.359
5	2000–2007	8	−22.915	−2.864	5	1907–1945	39	88.053	2.258
6	1751–1765	15	−31.283	−2.086	6	1866–1871	6	24.606	4.101
7	1773–1782	10	−26.083	−2.608	7	1762–1772	11	24.845	2.259
8	1860–1865	6	−17.364	−2.894	8	1883–1892	10	23.352	2.335
9	1841–1848	8	−18.939	−2.367	9	1833–1840	8	20.740	2.592
10	1967–1977	11	−21.652	−1.968	10	1743–1750	8	19.541	2.443

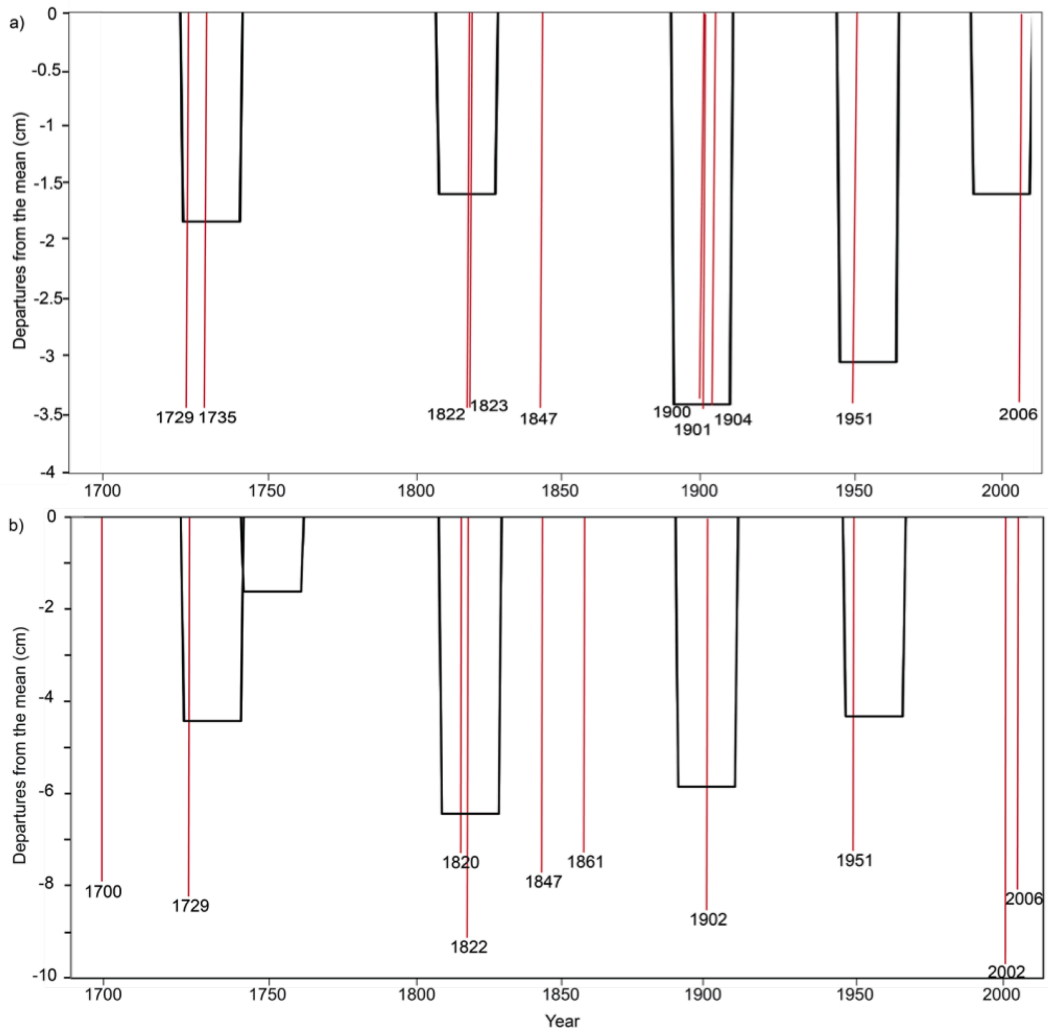

Fig. 5. Snow droughts in the a) CHU Chuska mountain reconstruction and b) WSR Williams Ski Run reconstruction. Black boxes are the average deficit for the 5 driest 20-year periods. Red lines are the driest ten single years in each reconstruction.

differences between the instrumental datasets. Overall, using just the WSR record, one would conclude that the drought was far more severe than if using the CHU record. This is exemplified by the magnitude of 2002 low snowpack at WSR, which is half of the SWE observed in the Chuska Mountains for that year. These differences underscore the importance of evaluating observed datasets for use-inspired research when stakeholders need science specific to locally-driven climate questions.

4.2. Evaluating the tree-ring reconstructions

Our tree-ring reconstructions skillfully estimate observed March SWE, but differences in two reconstructions may prove meaningful to NWMB. The WSR reconstruction shows slightly more explanatory power ($R^2 = 0.47$ vs $R^2 = 0.41$), so it provides slightly more accurate information about snowpack variability from one year to the next. The CHU reconstruction is relatively effective at capturing individual extremely dry years found in the calibration data. It does not capture the severity of 2006 as well as the Williams Ski Run reconstruction does, even though 2006 is extremely dry in both instrumental data series. But, the CHU reconstruction does capture the dry year 1990 in the Chuska Mountains, which was only an average year in the WSR instrumental data. In southwestern US states such as Arizona, Utah and Colorado, 2002 is associated with much below normal to record-low precipitation (e.g. Breshears et al., 2005; Williams et al., 2013). Reflecting this, 2002 was a snow drought year in both the WSR calibration and reconstruction series. The Chuska Mountains also experienced snow drought in 2002, but as is consistent with other local instrumental records observed in New Mexico, 2002 was not exceptionally dry in the Chuska Mountains. The reconstruction also reflects this difference.

Decadal to multi-decadal periods of low snowpack found in the reconstructions are consistent with other studies in the region. Three severe SWE droughts in the WSR reconstruction 1728–1744, 1818–1834, and 1893–1908 also rank highly in a cool-season precipitation reconstruction for the Four Corners (Faulstich et al., 2013). The second highest-ranking dry WSR snowpack period (1728–1744) and the highest-ranking CHU snowpack period (1729–1742) are also the highest-ranking cool-season drought in the Faulstich study. This drought corresponds with social upheaval in northwestern New Mexico and with a long-duration dual-season drought (cool-season and warm-season dry intervals occurring in the same year) in the region (Faulstich et al., 2013). Our findings are also consistent with studies that document pre-instrumental droughts that have been more intense or longer-lasting than dry periods of the 20th century (Woodhouse and Overpeck, 1998; Novak, 2007). Reconstructed October-July precipitation in the southern Colorado Plateau reveals coherent cool-season deficits between the Williams Ski Run record and a broader record for north central Arizona and south central Utah (Salzer and Kipfmueller, 2005). The cool-season drought beginning in 1818 is the most severe cool-season drought in the southern Colorado Plateau, ranked the most severe snow drought in the WSR reconstruction, and it is extremely dry in the CHU reconstruction. The 1818 drought coincides with widespread fire activity in the study area (Guiterman et al., 2019). Two other low snowpack periods ranking among the ten lowest in both reconstructions also rank among the most severe cool-season droughts in the southern Colorado Plateau region, 1890s–1900s and 1750s–1760s. While rank and duration of dry periods compared between these studies are generally consistent, differences may be attributed to i) differing drought-period thresholds defined in each study, ii) that this study focuses only on SWE rather than other climate variables, or iii) the variations in local SWE signals. Some variation in rank and duration between studies is expected, but our SWE reconstructions generally agree with the previous work mentioned above demonstrating reconstruction skill and regional coherence in cool-season drought.

4.3. SWE reconstruction implications for local water resources

The CHU and WSR reconstructions in this study show that some past snow droughts were of greater magnitude than severe snow droughts of recent memory. Further, both reconstructions reveal the presence of extremely dry years embedded in longer dry periods, some of which coincide with documented impacts to Navajo water resources in the 20th and 21st centuries. Extremely dry periods present in the paleo record, often more severe than what has been experienced in the instrumental record, coincided with impacts to human civilization (Cook et al., 2007). These impacts include societal disruptions in the Navajo region during periods of coinciding cool- and warm-season drought (Faulstich et al., 2013).

Despite its significant recent impacts, the 2000s drought is ranked as only the sixth driest run in the CHU reconstruction, is only half or less the duration of the 1700s, early 1900s, and 1950s droughts, and has a magnitude (running SWE total of years with snowpack below the mean) 50–75% less severe than these others. In addition to deficits in the 2000s, drought impacts experienced during the 1950s still resonate with Navajo living at the time (Novak, 2007; Redsteer, 2011). Although the year 1951 is among the driest individual years in both reconstructions, and the lengthy mid-century dry interval is of notably long duration, the 1950s are rivaled and exceeded by other dry snowpack periods when compared to the past 300 years. The magnitude of the 1950s drought in the WSR reconstruction is only 67% of the magnitude of the highest-ranking droughts in the same record, 1818–1834 and 1728–1744. While the 1950s drought in the Chuska Mountains is longer and of larger magnitude in the CHU reconstruction compared with the WSR reconstruction, its overall intensity is rivaled by the early 1900s drought and the mid-18th century drought.

Now with a record of Chuska snowpack variability over the last three centuries, the relationship between water scarcity and snow drought can be considered. Extreme water scarcity experienced since the early 2000s on the Navajo Nation (Redsteer, 2011) is largely attributed to warming and drying, but water scarcity may have been blunted by concurrent years with above average snowpack (i.e. 2001 and 2005). Persistent snowpack supports recharge of surface water, groundwater, and springs (Ferguson et al., 2011; Lani Tsinnajinnie, Assistant Professor University of New Mexico personal communication), but years or decades when snowpack remains low and more likely to disappear earlier in the spring may worsen already persistent water shortages. Crimmins et al. (2017) showed a shift during the 2000s in 50% cumulative total annual precipitation to later in the spring relative to the 1950s. Precipitation that arrives later in spring is more likely to fall as rain instead of snow, which can accelerate runoff timing. As a result, reduced snowpack and more precipitation falling as rain is less likely to moderate drought impacts in the Chuska Mountains in the way that persistent snowpack does. Impacts of such changes could be severe for the Navajo.

The NWMB will use the information provided in this study as a benchmark for exploring the impact of snow drought severity and duration on water scarcity, and to supplement newly developed snow monitoring efforts throughout the Navajo Nation. Future research efforts will compare results of this study to existing instrumental records of Chuska stream and spring water. To assess the strength of the snowmelt-runoff relationship in the Chuska setting, average March SWE could be correlated with Chuska streamflow records. Such comparisons could be extended into the paleo timeframe by developing proxy-based reconstructions of these water sources. At the same time, the relative influence of climatic variables such as seasonal precipitation, temperature, and evaporative demand on Chuska surface water variability will be evaluated. In combination with annual peak flow derived from streamflow records, this study could also compliment future research assessing shifts in the seasonal timing of maximum SWE. All of these efforts would utilize existing records, so continued monitoring of Chuska hydroclimate is essential to lengthen existing records and boost robust statistical analysis.

4.4. Assessment of the collaborative development of climate information

This research followed a process meant to lend legitimacy (Clark et al., 2002) to the production of climate information, and to develop a final SWE reconstruction product that is beneficial and readily usable to Navajo water managers. Our efforts to develop climate information for NWMB were individualized to NWMB practices and targeted at the local scale (McNie, 2007; Lemos et al., 2012). We worked actively with Navajo water managers to identify research needs. Through collaboration we formulated the research question that effectively aligned with NWMB needs, and were also within the capabilities of the researchers. Over a two-year period, there were eight in-person visits to the NWMB offices, with four expeditions to the Chuska Mountains. These visits consisted of meetings and discussions with NDWR staff about their water resources questions and involved brainstorming approaches to work together to try to answer those questions. During initial meetings we articulated data acquisition requirements and viewed relevant documents that were made available to us. During subsequent meetings, we visited remote Chuska snowcourse and SNOTEL sites. Meetings were organized with Navajo researchers who were concurrently conducting climate research in the Chuska Mountains, and with Margaret Hiza-Redsteer, U.S. Geological Survey staff scientist, who investigates increasing aridity in northeastern Arizona (e.g. Redsteer et al., 2011). We held interim workshops and meetings to ensure water managers were aware of the research, methods, direction, and progress. These meetings were useful to assess whether the evolution of the research answers the research questions, and served to iteratively exchange results and ramifications of the results. We rigorously vetted possible reconstructions and followed scientific protocols that assure credibility (McNie, 2013). For example, we followed standard dendrochronological procedures and statistical tests, as well as presented the research to the scientific community. Results and data were transferred to the community by way of the NWMB for their specific use (Chief et al., 2016) and through a results webpage[2] The climate information generated through this research was presented to the tribal community at large in two settings, i) at the 2017 Navajo Nation Department of Natural Resources conference near Flagstaff, Arizona and ii) an organized tour of the Navajo forest, where a cadre of scientists joined natural and cultural resource managers as well as community members from the Navajo Nation to discuss aspects of climate vulnerability, including issues and opportunities in water management for the Chuska Mountains.

It can be difficult to identify and quantify the effectiveness of climate services after the science products are provided to the decision-making partners. Despite high levels of interaction with NWMB, organizational and material limitations on both the Navajo and academic partners could have constrained the scale of the application of our

[2] Becky Brice, Chuska Mountains, Navajo Nation –https://npsbec.wixsite.com/coplathydroclim/chuska-mountains-navajo-nation.

reconstructions (Wall et al., 2017; Lemos et al., 2012). For this reason, we evaluated the reconstructions in terms of the information that they provide. While working closely with NWMB agency representatives we were able to increase comprehension and refine relevance of this information in real-time. At the same time, the researchers received direct confirmation from the representatives concerning their perception of their own understanding of the information. Our outputs include two new data series representing local and regional scale reconstructions providing statistically robust and long-term climate information that did not exist prior to the study. The two-series reconstruction approach developed in a collaborative context should motivate the users of our climate information to evaluate results in terms of application and relevance, though evidence to that effect will take time to develop. The comparative approach used here also provides a richer context for climate information situating local snowpack variability in the surrounding climate and illuminates limitations and benefits of employing various information resources at different scales. The two-reconstruction approach suggests the need for additional similar research in a region where instrumental climate information is historically limited. This research also highlights the need for strategic research collaborations between tribes and academic institutions informed by climate services research and that increase the range of uses of climate information derived from user-specified research questions (Lemos et al., 2012; David-Chavez and Gavin, 2018).

5. Conclusion

This study is a case study of use-inspired science driven by the expressed need for climate information in the context of severe drought and declining water resources on the Navajo Nation. We worked in partnership with the NWMB to place a relatively short snowpack record into a centuries-long context using tree rings while producing climate information that is both relevant and useful for NWMB managers.

Snowpack information developed from two reconstruction models - one for the Chuska Mountains (CHU) and one for Williams Ski Run (WSR) – reveal only slight differences in the ability of the individual reconstruction models to capture the variability present in the observed data. Both reconstructions show similar patterns of high and low frequency variability over a common 321 year period. In general, the WSR reconstruction reflects prolonged periods of above or below average conditions that are also present in the CHU reconstruction. The WSR reconstruction was able to demonstrate greater accuracy in estimating regional SWE values. However, despite concerns about the shorter length of the CHU record (30 years) the reconstruction model calibrated on this record was still able to capture 40% of the variance in SWE in the Chuska Mountains, was generally consistent in reflecting SWE variation in the respective observed record, and more effectively captured the duration, magnitude and timing of recent droughts having an effect on the people living in the region. For these reasons, our results indicate that the local Chuska Mountain reconstruction has greater potential to be relevant and useful climate information to the NWMB.

CRediT authorship contribution statement

Becky Brice: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing - original draft, Visualization, Project administration, Funding acquisition. **Christopher H. Guiterman:** Methodology, Software, Validation, Data curation, Writing - review & editing, Project administration. **Connie Woodhouse:** Validation, Writing - review & editing, Supervision. **Carlee McClellan:** Conceptualization, Validation, Resources, Writing - review & editing, Project administration. **Paul Sheppard:** Validation, Data curation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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