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Reconstructed cool- and warm-season precipitation over the tribal lands of northeastern Arizona

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Abstract For over a decade, the Hopi Tribe and Navajo Nation of northeastern Arizona have suffered the effects of persistent drought conditions. Severe dry spells have critically impacted natural ecosystems, water resources, and regional livelihoods including dryland farming and ranching. Drought planning and resource management efforts in the region are based largely on the instrumental climate record, which contains a limited number of severe, sustained droughts. In this study, a new network of moisture-sensitive tree-ring chronologies provides the basis for evaluating the longer-term temporal variability of precipitation in the Four Corners region. By analyzing the earlywood and latewood components within each annual tree ring, we are able to generate separate, centuries-long reconstructions of both cool- (October-April) and warm-season (July-August) precipitation. These proxy records offer new insights into seasonal drought characteristics and indicate that the instrumental record fails to adequately represent precipitation variability over the past 400 years. Through the use of two different analysis techniques, we identify multiyear and decadal-scale drought events more severe than any in the modern era. Furthermore, the reconstructions suggest that many of the historically significant droughts of the past (e.g., 17th century Puebloan drought) were not merely winter phenomena, but persisted through the summer season as well. By comparing these proxy records with historical documents, we are able to independently validate the reconstructions and better understand the socioeconomic and environmental significance of past climate anomalies on the tribal lands of northeastern Arizona.

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1 Introduction

For much of the 21st century, severe and persistent drought conditions have plagued the southwestern United States (e.g., Cook et al. 2010; Woodhouse et al. 2010). Droughts are common to the region, but the persistent nature of the ongoing drought has spurred renewed interest in improving our understanding of the region's natural climate variability. The socioeconomic and environmental impacts of this drought are especially marked in regions where the inhabitants' culture and economy are closely tied to climate-sensitive resources. For the dryland farmers and ranchers of the Hopi Tribe and Navajo Nation, the effects of drought have been disproportionately severe. These sovereign nations, who occupy roughly seven million hectares of land in the Four Corners region (Fig. 1), have endured persistent drought impacts for over a decade. Prolonged dryness has led to deteriorating rangeland conditions, losses of livestock, crop failures, local water shortages, reduced water quality and increases in airborne dust and pollutants (NDMC 2006; NNDWR 2003; Knutson et al. 2007; Ferguson et al. 2011).

In response to these impacts, tribes in the region are taking steps to address potential vulnerabilities and plan for drought adaptation in the face of a warmer, drier future. A more complete history and characterization of regional drought could allow resource managers to identify current changes in climate and develop appropriate mitigation and response strategies (e.g., Woodhouse et al. 2010). Tribal drought planning efforts are currently based on

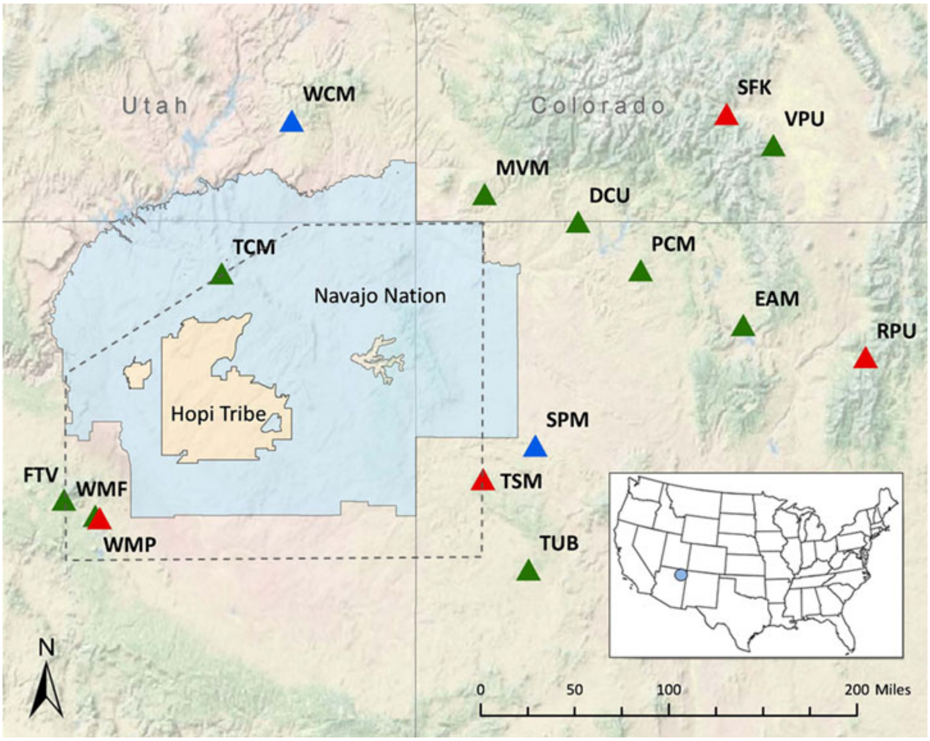

Fig. 1 Locations of earlywood and latewood tree-ring chronology sites (*all triangles*), predictors used in warm-season precipitation reconstruction (*red triangles*) and predictors used in cool-season reconstruction (*blue triangles*). *Dashed line* represents the reconstruction target area polygon, from which PRISM data were extracted (see text for details). Hopi Tribe and Navajo Nation boundaries are based on US Census 2000 data

the instrumental climate record, which spans at best, 120 years. The number and severity of drought events witnessed during this period are limited, thus restricting the ability of resource managers to plan around the full range of past hydroclimatic variability. Fortunately, this region contains abundant moisture-sensitive tree-ring records, which are ideal for extending records of climate variability into the past.

The Four Corners region (defined in this paper as the area shown in Fig. 1) contains a rich history of tree-ring research, starting with Andrew E. Douglass, the 'Father of Dendrochronology.' Douglass' early investigations of tree growth and climate relationships in northern Arizona opened a new field of inquiry by demonstrating that ring widths could be used as proxies for past climatic fluctuations (Douglass 1914). In the century since, tree-ring research has provided great insight into the paleoclimatic and environmental history of the southwestern U.S. (e.g., Rose et al. 1981; Dean 1988; D'Arrigo and Jacoby 1991; Woodhouse 2003; Salzer and Kipfmueller 2005; Touchan et al. 2011). However, the vast majority of dendroclimatic reconstructions for the Southwest are based on total ring-width chronologies, which primarily reflect the influence of winter-spring (cool season) precipitation on the annual water balance (St. George et al. 2010). This focus on cool-season conditions has restricted our knowledge of summer monsoon variability; a key component of the regional climate system (e.g., Douglas et al. 1993; Adams and Comrie 1997; Sheppard et al. 2002). To date, no summer (warm season) precipitation reconstructions have been tailored to the tribal lands of the Four Corners region. Gaining insight into monsoon rainfall fluctuations over past centuries would greatly complement our more extensive knowledge of cool-season precipitation and seasonal drought variability in the region.

Variations in the sub-annual increments of a tree ring (earlywood and latewood) can be utilized to provide information about both cool- and warm-season climate variability. However, a relatively limited number of southwestern studies have investigated the climate response of these individual components (Cleaveland 1986; Meko and Baisan 2001; Sheppard and Wiedenhoeft 2007; Therrell et al. 2002; Stahle et al. 2009; Griffin et al. 2011). Light colored earlywood (EW) is generally formed in the late winter to early spring, while dark colored latewood (LW) is formed in the late spring to summer. Because rainfall distribution is strongly bimodal in the Southwest (Sheppard et al. 2002; Hereford and Webb 1992), the widths of these sub-annual ring components are proportional to moisture availability during their season of formation. By measuring these EW and LW widths individually, it is possible to produce independent proxy records of both cool- and warm-season precipitation variability.

Understanding seasonal rainfall variability on the tribal lands is critical since the region's economic and environmental systems are highly adapted to a bimodal precipitation regime (Schwinning et al. 2008; Knutson et al. 2007). Gridded climate data (Daly et al. 2008) indicates that over one-third of the mean annual precipitation in the Four Corners region (225 mm) is delivered in the form of monsoonal storms during July and August, while winter-spring precipitation (October through April) accounts for nearly half of the total annual rainfall. Winter precipitation is vital for replenishing soil moisture, providing mountain snowpack that feeds aquifers, and driving vegetation productivity (Bradfield 1971; Comstock and Ehleringer 1992). Albeit less intuitive, summer monsoon precipitation is also crucial for this region, through its modulation of rangeland conditions, crop yields and water demand (Ray et al. 2007; Cable 1975; Eakin and Conley 2002). Hopi corn, for example, is dependent on spring snowmelt for germination, but relies on monsoon rains for its main growth and maturation (Bradfield 1971; Benson et al. 2007). Given the critical importance of seasonally specific rainfall to livelihoods, ecosystems, and natural resources on the tribal lands, paleoclimate records of both cool- and warm-season precipitation could provide useful insights for long-term planning.

This study uses a new network of EW and LW tree-ring chronologies and instrumental precipitation data from the tribal lands to produce reconstructions of both cool- and warm-season rainfall. The reconstructions are analyzed in order to: 1) identify and characterize multiyear droughts and decadal-scale precipitation regimes, 2) investigate drought seasonality, specifically focusing on episodes of simultaneous cool- and warm-season drought, and 3) frame the instrumental era droughts in a longer-term context. Two different methods (runs analysis and intervention analysis) are used to identify droughts, and a multivariate ranking technique is employed to evaluate the characteristics and relative significance of each event (Biondi et al. 2002). Lastly, historical records are used to independently validate the precipitation reconstructions and assess the socioeconomic circumstances that coincided with notable periods of persistent drought and wetness on the tribal lands.

2 Data and methods

2.1 Tree-ring and climate data

A network of nine Douglas-fir (*Pseudotsuga menziesii*) and six ponderosa pine (*Pinus ponderosa*) chronologies from the Four Corners region were updated through the 21st century for this study (Fig. 1; Table S1; Online Resource 1.1). EW and LW widths were measured on both the archived and newly collected tree-ring samples following the protocol described by Griffin et al. (2011). Numerical chronologies were computed using standard techniques in dendrochronology (e.g., Fritts 1976; Cook and Peters 1981), and LW indices were adjusted for their dependence on prior EW using methods described by Meko and Baisan (2001). Total monthly precipitation data from the Parameter-elevation Regressions on Independent Slopes Model (PRISM) dataset (Daly et al. 2008) were extracted from a polygon surrounding the tribal lands for the period 1895–2010 (Fig. 1). Based on the climate signal embedded in the sub-annual ring widths, seasons were defined as October-April (cool season) and July-August (warm season; Online Resource 1.2).

2.2 Climate reconstruction

Stepwise multiple linear regression was used to generate reconstruction models by calibrating the tree-ring chronologies with seasonal precipitation data over their common period (1896–2008). ‘Leave-one-out’ cross-validation was employed to validate the models, along with a suite of validation statistics as described in Online Resource 1.3 (e.g., Michaelsen 1987; Fritts 1976). The cool-season reconstruction explained 52 % of the variance in the instrumental precipitation record, while the warm-season reconstruction accounted for 42 % of the variance in the instrumental record (Table 1; Fig. S1). The models were then used to produce two seasonal reconstructions spanning the period 1597–2008 (Fig. S2).

3 Analysis of reconstructions

3.1 Cool- and warm-season multiyear droughts

Based on runs analysis (Salas et al. 1980), a multiyear drought was defined in this study as any period when precipitation fell below the long-term reconstruction mean for two or more consecutive years. Using this criterion, 44 multiyear drought events were identified for the

Table 1 Reconstruction model calibration and validation statistics (as defined in Online Resources), predictor chronologies, and regression equations for reconstructions. EW predictor chronologies are denoted with an 'e' subscript, LW predictor chronologies are denoted with an 'l' subscript

	Calibration statistics			Validation statistics				
Climate variable	R^2	R^2_a	SE	RE	RMSE	Sign Test (hit/miss)	Predictor chronologies	Period
Cool season (Oct-Apr)	0.524	0.515	31.04	0.500	31.50	92/21[a]	SPM_e WCM_e	1349–2008
Warm season (Jul-Aug)	0.443	0.422	19.81	0.370	20.57	83/30[a]	WMP_l RPU_l TSM_l SFK_l	1597–2008

Estimated warm-season rainfall$=-0.6732+1.0982(WMP_l)+1.2237(RPU_l)+0.8160(TSM_l)+0.4744(SFK_l)$

Estimated cool-season rainfall$=0.8830+1.7006(SPM_e)+1.8761(WCM_e)$

[a] significant at $p<0.01$

cool season and 55 for the warm season (Fig. 2). These episodes were further quantified in terms of three parameters: 1) *duration*—the number of consecutive years below the mean, 2) *magnitude*—the cumulative precipitation deficit for a given duration, and 3) *intensity*—the magnitude divided by duration, or average magnitude of an event (Biondi et al. 2002; Gray et al. 2004). Following the methods outlined by Biondi et al. (2002), we ranked each of the numerical parameters and then calculated an event 'score' for each drought by summing the overall rankings for each event. The scores provided an objective method for ranking the 'worst' or 'most remarkable' droughts in the record, with the lowest scores indicating the strongest or most severe events overall. Based on these scores, we identified the ten worst cool- and warm-season droughts in the reconstructions (Table 2).

Starting with the modern era, the event scores indicate that the warm-season precipitation deficit from 2002 to 2006 is ranked 9th most severe in the full reconstruction (tied with 1820–1822). The severity of this event provides perspective on recent drought conditions in the region, which have been further intensified by warming temperatures (e.g., Weiss et al. 2009). Three cool-season droughts from the instrumental period score among the top ten events, two of which occurred in the 1950s. Putting it in context, these 20th century dry periods are ranked as the 5th, 6th and 9th (tied with 1893–1894) worst droughts in the last four centuries. It should also be noted that the year 2002 contained the second driest cool season in the entire reconstruction.

In the years prior to the instrumental era, a wider range of drought variability is represented (Table 2). For example, relative to other events, the top-ranked summer drought of 1778–1783 was particularly sustained (6 years), while the top-ranked winter drought of

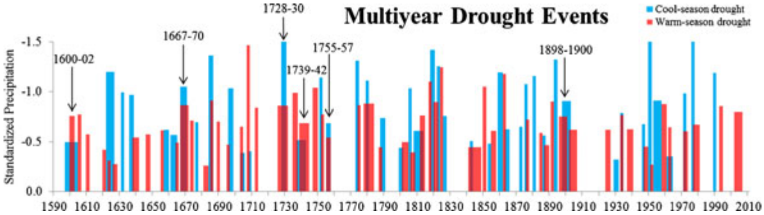

Fig. 2 Reconstructed warm-season (*red*) and cool-season (*blue*) multiyear drought events, 1597–2008. *Bar widths* represent drought duration and *bar heights* indicate drought intensity (average annual deficit). *Arrows* indicate dual-season droughts lasting 3 or 4 years

Table 2 Top ten most severe reconstructed warm- and cool-season multiyear droughts and their corresponding characteristics (as defined in text). Drought characteristics are expressed as average z-scores during each event, computed by subtracting long-term mean and dividing by standard deviation

Reconstructed Warm-Season Droughts						Reconstructed Cool-Season Droughts					
Rank	Years	Magnitude	Duration	Intensity	Score	Rank	Years	Magnitude	Duration	Intensity	Score
1	1778–1783	−5.29	6	−0.88	14	1	1728–1730	−5.02	3	−1.67	8
2	1707–1708	−2.94	2	−1.47	18	2	1622–1626	−6.01	5	−1.2	13
3	1667–1671	−4.34	5	−0.87	19	3	1818–1820	−4.27	3	−1.42	14
"	1726–1731	−5.17	6	−0.86	19	4	1684–1686	−4.1	3	−1.37	17
"	1747–1749	−3.12	3	−1.04	19	5	**1950–1951**	−3.3	2	−1.65	19
6	1735–1737	−2.96	3	−0.99	22	6	**1976–1977**	−3.13	2	−1.57	21
7	1824–1825	−2.5	2	−1.25	24	7	1859–1861	−3.59	3	−1.2	25
8	1862–1863	−2.37	2	−1.18	26	8	1667–1670	−4.2	4	−1.05	26
"	**2002–2006**	−4.03	5	−0.81	26	9	1893–1894	−2.65	2	−1.33	28
10	1820–1822	−2.69	3	−0.9	28	"	**1953–1957**	−4.56	5	−0.91	28

1728–1730 was notably intense (−1.67). Three warm-season droughts scored the same for overall severity (third worst); however, their individual characteristics varied widely. For example, the drought of 1726–1731 lasted twice as long but was less intense than one that occurred several decades later (1747–1749). Similarly, the 1893–1894 cool-season drought scored the same as the five-year 1950s drought, but the 1950s event was more prolonged and less intense. According to the reconstructions, the modern period (1900–2008) was characterized by warm-season droughts that were more frequent but less intense than cool-season droughts (Table S3). This pattern appears stable back through the pre-modern period (1597–1899). Average drought duration, on the other hand, was roughly equal between the two seasons over the full reconstruction period.

Further inspection of the tree-ring records reveals that 'dual-season' or 'interseasonal' drought (below-average precipitation during both seasons of the same year) occurred 98 times in the past 412 years, 24 % of the reconstructed record length. In other words, dry winters were followed by failed monsoons for nearly one quarter of the past four centuries. The majority of these droughts lasted for only one year (60 of 98 events), but up to four consecutive years of interseasonal droughts may have occurred in the past (1667–1670 and 1739–1742). This analysis indicates that some of the more remarkable cool-season droughts were actually dual-season events. For example, the highest ranking cool-season drought (1728–1730) persisted through the warm-season as well, with a similar magnitude but longer duration. The infamous 'Puebloan drought' of the late 1660s (Levy 1992; Sauer 1980; Parks et al. 2006; Cook et al. 2007) ranked 3rd for the summer and 8th for the winter; though its intensity and duration were similar across the two seasons. A clustering of protracted dual-season droughts (lasting three or four consecutive years) are apparent in the first half of the 18th century (1728–1730, 1739–1742 and 1755–1757), which appears anomalous over the full reconstruction period (Fig. 2). Although the tribal lands may not have experienced sustained interseasonal drought since the turn of the 20th century, these findings highlight the possibility of such an episode recurring in the future.

3.2 Decadal-scale precipitation variability

While runs analysis is useful for examining short-term droughts, it does not adequately capture decadal-scale shifts in mean condition. For example, the impacts associated with the 1893–1906 drought persisted for well over 10 years, but runs analysis classifies this episode as two separate events due to reconstructed average precipitation in 1901. In terms of water resources, 1 year or season of average rainfall will not alleviate a decade's worth of drought impacts; therefore, identifying these sustained periods of dryness in the proxy records provides a more complete picture of drought history in the region. To detect these statistically significant regime shifts in the reconstructions, a modified version of intervention analysis (Box and Tiao 1975) was employed. In contrast with traditional applications of intervention analysis, this technique was used to identify prolonged 'pulses' of dryness or moisture in the reconstructions (see Pederson et al. 2006 for methods), rather than continuous 'steps' or shifts in climatic regime (as in Gray et al. 2004).

Several prolonged dry periods are evident from this analysis (Fig. 3), the extents of which were not captured with the previous method. The 1950s event aside, the modern era has been characterized not by sustained drought but rather by periods of prolonged wetness (1905–1923 and 1978–1993). In contrast with the findings of Stahle et al. (2009), who documented dual-season drought in western New Mexico, this analysis indicates that the 1950s drought was predominantly a cool-season phenomenon on the tribal lands, with periods of near-normal monsoon rainfall possibly helping to mitigate the extended winter-spring drought.

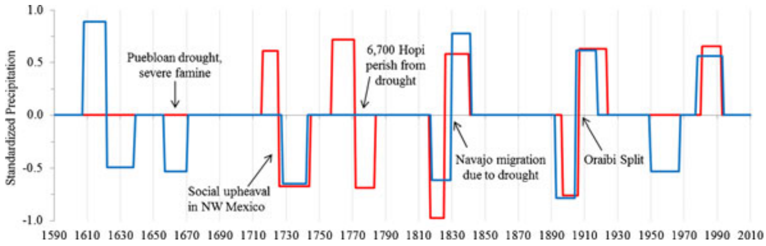

Fig. 3 Intensity (*height*) and duration (*width*) of significant warm-season (*red*) and cool-season (*blue*) decadal-scale precipitation regimes identified in the intervention analysis. Notable historical events are annotated

The pluvial of the early 20th century was preceded by a dry interval during the 1890s and early 1900s, with the cool- and warm-season droughts showing roughly equal severity (Fig. 3). A similar pattern of dual-season drought and pluvial is observed nearly a century earlier (1817–1831). The most severe drought in both seasons lasted from approximately 1725 to 1745 and was unprecedented in terms of magnitude and duration for consecutive seasons. Several decadal-scale summer events are evident throughout the 18th century, but none prior to 1716, whereas the winter-spring record is characterized by major drought episodes in the mid-seventeenth century (including the 14-year long Puebloan drought) and a sustained wet period in the early 1600s.

The cool-season droughts identified in this study are consistent with those found in previous tree-ring reconstructions from the region (see Online Resource 2). For example, all of the decadal-scale periods of above- and below-average rainfall estimated in this analysis (along with eight of the top ten multiyear droughts) correspond with dry episodes on the southern Colorado Plateau, as reconstructed by independent chronologies (Salzer and Kipfmueller 2005). Furthermore, a July precipitation reconstruction from western New Mexico (Stahle et al. 2009) provides independent verification of our warm-season droughts.

Collectively, the cool- and warm-season reconstructions presented here suggest that many of the well-documented drought events in the region were not merely winter phenomena, but persisted through the summer season as well. This additional layer of information represents a substantive advancement in our understanding of the past climate on tribal lands in the Four Corners region.

4 Discussion

Given the evidence of severe dual-season drought at both the interannual and decadal timescales in the reconstructions, we asked the question, how did episodes of severe, dual-season drought affect past societies in the Four Corners region?

4.1 Insights into past drought from historical documents

The journals and reports from Spanish missionaries, soldiers and explorers during the colonial-era Southwest provide a rich source of historical data for better understanding the interactions between indigenous groups and their environment. A vast collection of Spanish-colonial documents has been translated and analyzed to gain knowledge of the cultures, customs and relations of past societies (e.g., Donaldson 1893; Hackett 1937), and a review of this work has revealed the historical and social significance of the tree-ring reconstructed droughts.

The Puebloan drought of the mid-17th century (which, according to this study, consisted of 14 years of below-average winter precipitation and 5 years of failed monsoons; Fig. 3; Table 2) is well-documented in the literature for its remarkable severity and socioeconomic impacts (e.g., Hackett 1937; Sauer 1980; Levy 1992). Compounded by famine, disease and Apache raids, the drought took a heavy toll on the Puebloans and Spaniards alike, forcing them to adopt such dire measures as consuming "[cow]hides and straps of the carts, preparing them for food by toasting them in the fire with maize and boiling them with herbs and roots" (Father Ayeta, 1679; qtd. in Hackett 1937). Fray Juan Bernal, an agent of the Inquisition, reported to the Holy Office that "for 3 years no crop has been harvested. Last year, 1668, a great many Indians perished of hunger, lying dead along the roads, in the ravines, and in their hovels. There were pueblos, like Las Humanas, where more than 450 died of hunger" (Hackett 1937). A yearly tribute of corn required by the Spanish colonizers is thought to have prevented the Puebloans from maintaining their customary three- to four-year food reserves during this time, thereby contributing to the dreadful famine (Sauer 1980; Parks et al. 2006). A few short years after this calamity, the Puebloans led a violent uprising against their Spanish colonizers, an event known as the Pueblo Revolt of 1680 (Knaut 1997).

Nearly 100 years later, the tribal lands were again plagued by drought, famine, smallpox and crop failures (Titiev 1944; Brugge 1994). According to our runs analysis, the period from 1778 to 1783 was characterized by the most severe warm-season drought in the last 400 years (Table 2), which was further exacerbated by a shorter, simultaneous cool-season drought (Fig. 2). Intervention analysis indicates that the below-average rainfall regime may have prevailed for as long as 12 years (Fig. 3). In September of 1780 (a year that was markedly dry in both seasons), Colonel Juan Bautista de Anza, governor of New Mexico, set out on a mission to relocate and convert a number of Hopi families. Upon arriving, he found that "the 40 families had been forced by hunger 15 days ago to go to the Navajo country, where the men had been killed and the women and children seized as slaves" (Donaldson 1893). Considerable evidence supports the notion that Hopi families migrated to remote regions during severe droughts (Levy 1992; Donaldson 1893; Stephen 1936). Short-term dry spells were often endured by farming distant fields, but during protracted events such as this one, large portions of the village would often seek refuge among other tribes for varying periods of time (Levy 1992). As further evidence of the drought's devastating toll, Governor Anza recounted that "in 1775 [Fray Francisco Silvestre Velez de] Escalante had found 7,494 [Hopi] souls; now there were but 798; no rain has fallen in 3 years and in that time deaths numbered 6,698. Of 30,000 sheep 300 remained, and there were but five horses and no cattle" (Donaldson 1893). This documentation reveals the truly harrowing consequences associated with consecutive years of summer drought punctuated by dual-season aridity on the tribal lands.

A more recent period of anomalous climate featured prominently in historical documents lasted from approximately 1893 to 1923 and consisted of a prolonged drought followed by a dramatic pluvial (Bradfield 1971). Right at the onset of this decade-long drought, a Hopi journal entry read, "Last summer and winter [1893] had little or no moisture and many of the elders were beginning to shake their heads in ominous doubt" (Stephen 1936). After nearly a dozen years of crippling drought, a deluge of "heavy rains swept away farms and cut the Oraibi Wash, lowering the water table" (Hoover 1930). In her memoir, Helen Sekaquaptewa (1969) recalls the fateful event when "the spring floods of 1907 ran uncontrolled for the first time. Erosion worked fast in the deep sandy soil. Before the men were returned, the channel of the Oraibi Wash was so deep that it was impossible to divert the water onto the land, and the cornland was lost forever. The wash now runs in a channel as deep as 30 feet in places, carrying the flood-waters swiftly away to the Little Colorado River." While there is some debate surrounding the cause of the Oraibi Split of 1906—a tumultuous time in Hopi history when half of the population left to form a new village—it is likely that these background climatic conditions played a role in the social unrest.

5 Conclusions

The earlywood and latewood chronologies developed for this study highlight a broader range of natural climate variability than is documented in the instrumental record. This work is distinct from most other regional dendroclimatic studies in that it provides both cool- and warm-season precipitation information. Building on the critical work of Stahle et al. (2009) that used a single chronology to reconstruct July precipitation for western New Mexico, this study uses a network of latewood chronologies to reconstruct July-August precipitation for the tribal lands of northeastern Arizona. Paired with the companion reconstruction of October-April precipitation, this study increases our understanding of North American monsoon variability and its relationship to cool-season precipitation in the Four Corners region.

Runs analysis was used to characterize and quantify drought events of past centuries in terms of magnitude, duration, intensity and relative importance, while intervention analysis allowed us to assess the frequency and timing of decadal-scale moisture anomalies. These analyses indicate that the instrumental record does not adequately represent the range of drought characteristics possible on the tribal lands. For example, the longest continuous run of seasonal drought during the modern period was 5 years, whereas the pre-modern period contained episodes of six, seven and eight consecutive-year droughts. Similarly, the 20th century, with only 9 winter and 12 summer droughts, contained fewer multiyear events than any other century. The uniqueness of the 20th century is further highlighted by the marked occurrence of protracted dual-season pluvials, rather than drought, over this period. Perhaps of greatest relevance, this study suggests that severe and sustained episodes of dual-season drought, which are largely missing from the instrumental period, have occurred multiple times in the past (e.g., 1660s, 1740s, 1890s).

The seasonality of rainfall regimes is crucial to the tribal societies and economies in the Four Corners region. Latewood-width chronologies developed for this study provide novel insights into the range of monsoon hydroclimate variability, which plays a critical role in regional livelihoods. Through comparison with documentary evidence, we were able to explore the juxtaposition of seasonal drought and societal impacts over past centuries. Lessons from this comparison may be relevant for ongoing efforts to sustainably manage the region's natural resources.

Lastly, these reconstructions offer the opportunity to evaluate the 21st century drought in a long-term context. Our tree-ring data indicate that as of 2008, the multiyear drought on the tribal lands was not yet more severe than persistent events of the 1950s, 1740s, or 1660s. However, as of 2012, the drought appears to be ongoing (U.S. Drought Monitor: http://droughtmonitor.unl.edu/monitor.html). The majority of droughts documented in the tree-ring reconstructions occurred under natural climate variability. In all likelihood, the warming and drying trends projected for the future (Christensen et al. 2007) will only serve to exacerbate the social and economic impacts of drought already felt by these tribal nations. By improving our understanding of the region's background climate fluctuations, we can frame current droughts in a longer context and inform resource management and drought planning decisions on the tribal lands.

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