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Extended Chronology of Drought in South Central, Southeastern and West Texas

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Abstract: Short instrumental climatic records prevent appropriate statistical and historical characterization of extreme events such as the extent, duration, and severity of multiyear droughts. The best solution is to extend climatic records through well-understood proxies of climate. One of the best such proxies is climate-sensitive annual tree rings, which can be dated precisely to the year, are easily sampled, and are widely distributed. We created 3 new baldcypress chronologies in South Central Texas and used them, along with existing Douglas-fir chronologies from West Texas and a composite post oak chronology in Central Texas, to calibrate 1931–2008 and reconstruct June Palmer Drought Severity Index (PDSI) in Texas climate divisions 5 (Trans Pecos), 6 (Edwards Plateau), 7 (S. Central), and 8 (Upper Coast) 1500–2008. We validated the reconstructions against observed data not used in calibration.

Most water planners in Texas at present use the drought of the 1950s, 1950–1956, as a worst-case scenario. Our reconstructions show, however, that a number of extended droughts of the past were longer and/or more intense than the 1950s drought. Furthermore, extended droughts have been a consistent feature of southwestern climate since the 800s, including at least 4 megadroughts 15- to 30-years long centered in central or northern Mexico (Stahle et al. 2009; 2011b). This and previous studies indicate that severe decadal-scale droughts have occurred in Texas at least once a century since the 1500s. Current use by water planners of the 1950s drought as a worst-case scenario, therefore, is questionable. When water managers consider past droughts, population growth, and climate change, it becomes highly probable that the future poses unprecedented challenges.

Keywords: Texas, drought of record, Palmer Drought Severity Index (PDSI), paleoclimatology, dendrochronology, tree rings, baldcypress

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Note: The University of Texas Austin Environmental Science Institute has a website about this project:
http://www.esi.utexas.edu/faculty/featured-research-projects/141-the-tree-project

Note: Texas Parks and Wildlife produced a short video called "Studying Cypress Trees, the Climate Detective – Texas Parks and Wildlife [Official]" about this project. It can be viewed at:
http://www.youtube.com/watch?v=zwPdfWahk4s

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INTRODUCTION

Limited water resources are a serious problem in Texas due to its partially semiarid drought-prone climate, particularly in West and Central Texas (Griffiths and Ainsworth 1981; Votteler 2000). The 1980 heat wave, the worst since 1895 by some measures in some climatic divisions (NCDC Climate Diagnostic Center 2011), caused some $1.5 billion in losses (Karl and Quayle 1981). The drought of the 1950s caused more than $3 billion (about $27 billion in 2010 dollars) in losses to the agriculture sector alone, excluding ranching (Lowry 1959). The more recent droughts of 2006, 2008–2009, and 2011 have also had devastating consequences for Texas agriculture (e.g., Jervis 2009; Parker 2011). The start of meteorological observations in Texas dates from the mid- to late-19th century, but this short record inadequately characterizes those events that occur irregularly, such as prolonged multiyear droughts (Namias 1981). Rodríguez-Iturbe (1969) has also demonstrated that very large numbers of observations may be needed to derive accurate statistical parameters for hydrometeorological phenomena. For these reasons it is highly probable that worse droughts than any seen in the instrumental record have occurred in the past (e.g., Stahle et al. 2000, 2007, 2011b) and such severe drought may have unforeseen consequences (e.g., that affect human health; cf. Acuna Soto et al. 2002).

Prompted by the 1950s drought, Lowry (1959) was commissioned to investigate drought in Texas through rainfall records of deficits. His investigation shows that drought can be highly localized or more widespread. Most of the droughts he reports on occurred in the areas we reconstruct and appear in our reconstructions, but some droughts occurred completely outside of the areas we have reconstructed. Lowry's (1959) report demonstrates that Texas is so large and has such a large precipitation gradient (Banner et al. 2010), that it is rare for the entire state to experience drought at the same time (Votteler 2000). Nevertheless, the whole state and much of the surrounding states can experience severe drought simultaneously, such as in 2011.

One means of overcoming the lack of historically observed climate data investigates long-term drought history through substitutes, or "proxies," for instrumental data. One of the best such proxies is tree rings because annually produced rings are often sensitive to climate, and such trees are widely distributed and readily available. Each ring can be dated precisely to the year in many long-lived trees due to the influence of climate on growth, and the climate information contained in the annual rings is relatively easy to extract from properly dated samples (Stahle 1996; Fritts 2001; Speer 2010).

The paleoclimate of Texas since the last glacial maximum has been investigated with several proxies (e.g., COHMAP Members 1988). Previous efforts to analyze the climate of Texas with proxy series include pollen studies (Bryant 1977; Bryant and Holloway 1985), floral and faunal fossils (e.g., Lundelius 1967; Graham 1976), strontium isotopes (Cooke et al. 2003), carbon isotopes (e.g., Nordt et al. 1994), magnetic susceptibility (Ellwood and Gose 2006), speleothems (e.g., Musgrove et al. 2001), and some of the tree-ring studies by Stahle and Cleaveland (1988, 1992, 1995), Stahle et al. (1985, 1988, 1998a, 1998b, 2007), Cleaveland (2000, 2004, 2006), Dunne et al. (2000), Dunne (2002), Mauldin (2003), and Fye and Cleaveland (2001). Except for the tree-ring studies, all of these methods of reconstructing climate provide lower resolution millennial to centennial scale paleoclimatic data, which give little indication about the extent of multiyear droughts.

The above tree-ring studies that were specifically concerned with Texas paleoclimate used central Texas chronologies but were limited to beginning in the mid- to late-1600s because they were based on post oak (*Quercus stellata* Wangenh.), which usually reaches a maximum age of less than 350 years. Even with the addition of post oak samples from historic buildings, the central Texas post oak record could only be extended to 1648 (Therrell 2000). Very long climate reconstructions of averaged June, July and August (JJA) Palmer Drought Severity Index (PDSI; Palmer 1965) on a 0.5° X 0.5° grid have been produced by Dr. Edward Cook of Lamont-Doherty Earth Observatory (Cook et al. 1999, 2007). Although Cook's gridded central Texas JJA reconstructions are up to 1,000 years long, they extrapolate central Texas climate from distant chronologies in far West Texas, New Mexico, and Louisiana (Cook et al. 1996, 1999, 2004; Cleaveland 2006). In addition, the best monthly PDSI variable to reconstruct in Texas is June, not a JJA average (Stahle and Cleaveland 1988; Cleaveland 2004). To improve central Texas reconstructions, we have produced 3 new local climate sensitive chronologies in South Central Texas that enable us to reconstruct climate 1500–2008.

Warm season drought in Texas is strongly linked to the strength of upper level high pressure that develops and persists in the southern United States and to atmospheric inversion caused by warm air transport from the Rocky Mountains and Mexican Plateau (Myoung and Nielsen-Gammon 2010b). These warm season droughts tend to persist because low soil moisture creates a feedback loop that inhibits convection, reducing warm season precipitation (Myoung and Nielsen-Gammon 2010a).

Evidence indicates that central and northern Mexico, the Southwest, and other regions of North America have experienced severe droughts ("megadroughts") since the 800s (Stahle et al. 2011b), particularly in the mid- to late 1500s and early 1600s (Stahle et al. 1998a, 2000, 2007; Cleaveland et al. 2003; Cook et al. 2007). Paleoclimatic investigations have helped find links in U.S. southwestern climate to global circulation features such as the El Niño/Southern Oscillation (ENSO) (Cleaveland et al. 1992; Stahle and Cleaveland 1993; Stahle et al. 1998b; Fye and Cleaveland 2001; Cook et al.

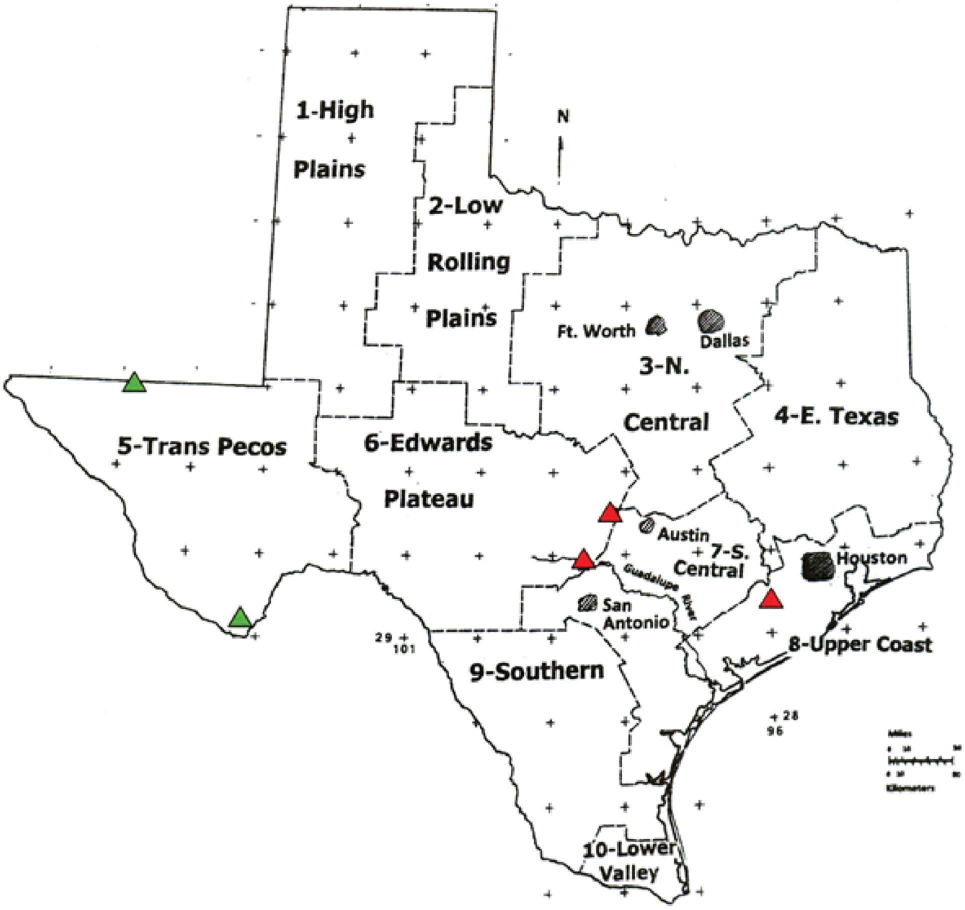

Fig. 1. Map of Texas, showing the climate divisions and chronology locations. June PDSI was reconstructed in climate divisions 5 (Trans Pecos), 6 (Edwards Plateau), 7 (S. Central), and 8 (Upper Coast). The red triangles are locations of baldcypress chronologies and the green triangles are locations of Douglas-fir chronologies. See Table A1 for the locations of the 7 individual chronologies averaged into the Central Texas post oak chronology.

2007; Stahle et al. 2011a). La Niña conditions, the cold phase of ENSO, cause drought across northern Mexico and the southern United States (Trenberth et al. 1998; Aguado and Burt 2007; Cook et al. 2007; Stahle et al. 2011a) and may play a role in extended droughts. La Niña conditions are characterized by below normal sea surface temperature (SST) in the eastern equatorial Pacific (Aguado and Burt 2007). Slade and Chow (2011) investigated the effects of La Niña and El Niño on central Texas precipitation and runoff. La Niña and El Niño each occurred about 25% of the time 1950–2009. Comparing La Niña and El Niño, La Niña August averaged more precipitation, June and July were about equal, and the other 9 months had less precipitation than El Niño. Mean streamflow was less year round under La Niña conditions at all gauges and the differences became greater farther south in central Texas (Slade and Chow 2011). Other patterns of SST, such as the Pacific Decadal Oscillation and the North Pacific mode, may play a role in modulating Texas climate on a multidecadal scale (Mantua et al. 1997; Nigam et al. 1999). Such links to recognized recurring circulation and SST features not only offer clues to the causes of multiyear drought; they also are one path to a reliable, long lead-time climate prediction capability (Barnston et al. 1994).

The negative impact of drought on past societies is undisputed, such as the depopulation of the Mesa Verde region because of drought in the late 1200s (e.g., Burns 1983; Stahle and Dean 2011; Stahle et al. 2011b). The case of climatic effects on modern civilization is more complicated because of the widespread detrimental anthropogenic effects facilitated by technology, e.g., "sod-busting" that led to the epic dust storms of the Dust Bowl era (Stahle and Dean 2011). Advanced societies also suffer from climate extremes but can mitigate the effects through advanced technology and organization (IPCC 2007a). This mitigation may become even more critical in the future because there is strong evidence that weather variability is being made more extreme by anthropogenic climate change

(Min et al. 2011; Pall et al. 2011; Schiermeier 2011).

Another factor is the increasing population of Texas. Since 1950 Texas population has grown from 7,711,194 to 25,145,561 (326% increase) and has experienced a 20.6% increase from 2000 to 2010 (Texas State Library 2011). A population growing at this rate will undoubtedly put stress on water resources regardless of the frequency and duration of future drought.

We have not analyzed the other end of the climate spectrum from drought: extreme wetness. There are several reasons for this. First, many of the most extreme effects of excess rainfall occur over short periods, with voluminous runoff that leads to little increase in soil moisture that trees can respond to. Second, some extreme events will occur when the trees are dormant, not during the growing season. Third, tree growth often responds less to wet conditions; when soil moisture is no longer the factor limiting growth of the tree, growth may become less synchronous among trees (Fritts 2001). Nevertheless, moisture surpluses can be reconstructed and analyzed (Woodhouse et al. 2005), e.g., the 20th century pluvial period, 1905–1917 that led to over-allocation of Colorado River streamflow (Stockton 1990). Even relatively short-duration floods can sometimes be detected and analyzed through anatomical evidence in tree rings (Yanosky 1983, 1984) and flood damage to trees (McCord 1990).

Ideally, water managers in Texas can use augmented knowledge about past climate extremes to outline realistic worst-case scenarios and prepare for them (Rice et al. 2009). Of course, an ill-advised water manager might even choose to use a lesser drought than the 1950s drought as the "drought of record" for planning purposes (Casteel 2005), despite evidence that such droughts or worse recur in the long-term. Improved estimates of climate variability and trends should prepare authorities to cope with ongoing climate change, which is predicted to increase aridity in the Southwest (IPCC 2007b; Seager et al. 2007; Banner et al. 2010) and may help them to prepare mitigation strategies (IPCC 2007a; Furniss et al. 2010). If climate does, in fact, change as has been predicted (IPCC 2007b), then many assumptions of water managers based on stationarity of climate will prove invalid (Milly et al. 2008). In fact, in view of the extreme variability of climate found in this and other paleoclimatic studies, the stationarity of climate has always been an illusion based on a short-term view of climate, prompted by concepts like the National Oceanic and Atmospheric Administration's (NOAA's) 30-year "climatic normals." Paleoclimatic studies enable us to appreciate the magnitude of this variability temporally and geographically.

CLIMATE RECORDS

In the following we refer to material contained in an appendix that is relevant to the research but is too voluminous to reside in the paper itself. Tables and figures contained in the appendix have the prefix "A", e.g., "Table A1" or "Fig. A3".

Precipitation, temperature, and PDSI (Palmer 1965) data for the Texas climate divisions begin in 1895 (Fig. 1; See map in Karl et al. 1983, p. 19; NCDC Climate Diagnostic Center 2011). The divisional climatic data often exhibit homogeneity that may be lacking in single stations, because the divisional data average all stations within the division, compensating for any problems that might occur at an individual station (Stahle and Cleaveland 1992). Computation of division averages began in 1931, while NOAA computes division averages from state averages before 1931 (Karl et al. 1983). Because divisional data exhibit better stability and represent larger areas than station data, in this research we investigated past climate in divisions 5 (Trans Pecos), 6 (Edwards Plateau), 7 (South Central), and 8 (Upper Coast) (Fig. 1).

We used the PDSI in our reconstructions of past climate. The PDSI incorporates temperature and precipitation, along with latitude, day length, and soil moisture capacity into a 2 level soil moisture model that is zero centered. Positive indices indicate above normal soil moisture, while negative indices indicate some degree of drought. The degrees of drought and wetness in the PDSI are designated as follows: 0.5 to -0.5 = near normal; 0.5 to 1.0 (-0.5 to -1.0) = incipient wetness (drought); 1.0 to 2.0 (-1.0 to -2.0) = mild wetness (drought); 2.0 to 3.0 (-2.0 to -3.0) = moderate wetness (drought); 3.0 to 4.0 (-3.0 to -4.0) = severe wetness (drought); >4.0 (<-4.0) = extreme wetness (drought) (Karl et al. 1983). The drought indices are standardized by taking into account local averages of temperature and precipitation, so that PDSI values will be comparable across different climate regimes (Palmer 1965; Karl et al. 1983).

The PDSI computation incorporates strong persistence from month to month. Consequently, the single value for June or July PDSI in Texas usually gives a good picture of moisture conditions for the entire growing season as well as precursor conditions during the previous winter that may affect growing season soil moisture. Upon occasion an unusual meteorological event, such as a slow-moving tropical depression, can deliver enough moisture in a short time to reverse a long drought trend (Stahle et al. 1985). Initiation of dry conditions, however, reverses wet conditions more gradually, due to the persistent nature of the soil moisture model (Palmer 1965). Therefore, PDSI seems a robust and appropriate measure of growing season climate and water resources that can be reconstructed from tree rings. Important for water resources, when PDSI values are negative, groundwater recharge will be reduced or eliminated altogether. Combined with increased reliance on groundwater in severe droughts, this means that aquifers will be used unsustainably in these periods (Slade and Chow 2011).

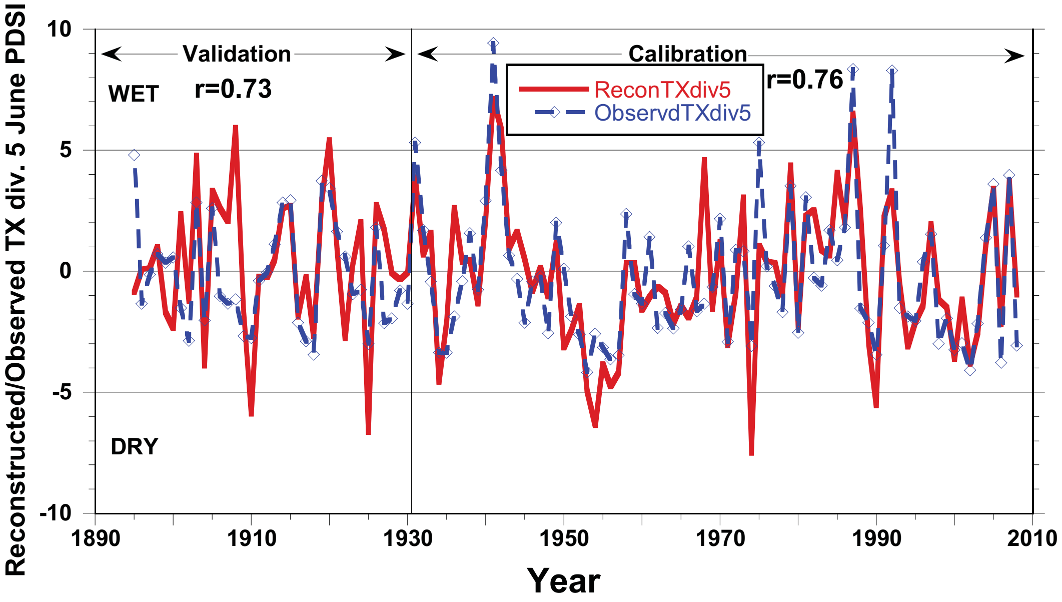

Fig. 2. Climate division 5 (Trans Pecos) June PDSI reconstructed (solid line) and observed (dashed line) series 1895–2008 (Fig. 1, Table A3). $R^2 = 0.580$.

TREE-RING CHRONOLOGIES

Seven post oak (*Q. stellata* Wangenh.) tree-ring chronologies, 3 from living trees and 4 from timbers of old buildings located in divisions 7 and 8 were averaged into a well replicated composite oak chronology for Central Texas (CENOAK) (Therrell 2000; Table A1). The averaged chronology begins in 1648 and ends in 1995. We extended the CENOAK post oak chronology 1996–2008 with regression estimates of the tree-ring indices derived from an average of the June PDSI in divisions 6, 7, and 8. In addition, on the basis of correlations, we chose 2 West Texas Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) chronologies, Guadalupe Peak National Park (GPM; 1362–2008) and Big Bend National Park (BSC; 1473–1992), for possibly reconstructing divisions 5, 6, and 7. We eliminated all the candidates from New Mexico (Table A1) based on their lack of correlation with Texas climate. We extended the indices of the Big Bend tree-ring chronology to 2008 with regression estimates derived from division 5 June PDSI. There is a small degree of circularity in using meteorological records to extend the shorter tree-ring chronologies to match the longest chronologies. We judge it to be minor, however, and preferable to restricting some of the calibrations to end in 1992, the ending date of the unextended BSC chronology.

Because the Central Texas post oak chronology has insufficient length to reconstruct the 1500s megadrought era (Stahle et al. 2000, 2007; Cleaveland et al. 2003; Cook et al. 2010), we collected 7 new sites and derived 3 new long baldcypress (*Taxodium distichum* (L.) Rich.) chronologies (Fig. 1; Table A2) that start in the 1400s. Baldcypress has been used to reconstruct climate in the United States with considerable success (Stahle et al. 1985, 1988, 1998a; Stahle and Cleaveland 1992, 1995; Cleaveland 2000). Because the chronologies began on different dates and had small sample sizes in the 1400s, we started our analyses at 1500.

METHODS

We crossdated tree-ring samples by pattern matching to detect and correct for missing and false rings (Douglass 1941; Swetnam et al. 1985; Stokes and Smiley 1996; Speer 2010). Dated samples were then measured with 0.001mm accuracy, and we checked the crossdating and measurement accuracy with correlation analyses (Holmes 1983; Grissino-Mayer 2001).

Most tree-ring series have growth trends that must be removed in order to create time series with stationary statistical properties that reflect climate influence more accurately than the undetrended ring widths. We transformed individual ring width series (in mm) with different means and nonstationary statistical properties into dimensionless indices with a mean of 1.0 and stationary statistical properties. We used a computer program (ARSTAN) (Cook 1985; LDEO website 2011) that transformed the ring widths then averaged the resulting indices into the ring width chronology and removed variance trend created by changing sample size (Shiyatov et al. 1990). See item 1 in the appendix for more detail.

To find the best variables for reconstruction, we correlated the chronologies with the monthly average temperature, total precipitation, and PDSI in each climate division (not shown).

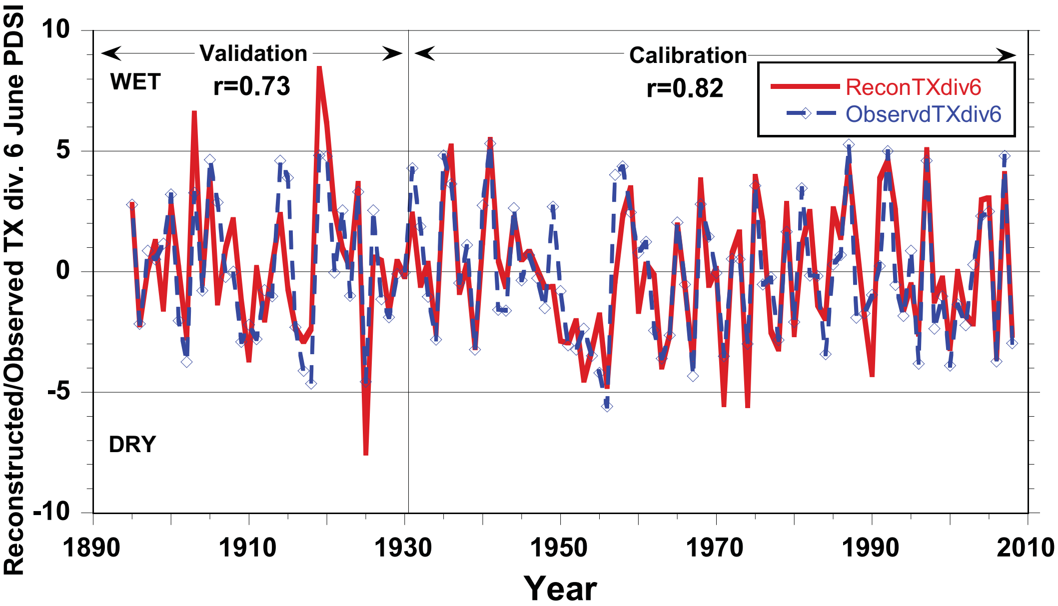

Fig. 3. Climate division 6 (Edwards Plateau) June PDSI reconstructed (solid line) and observed (dashed line) series 1895–2008 (Fig. 1, Table A4). $R^2 = 0.674$.

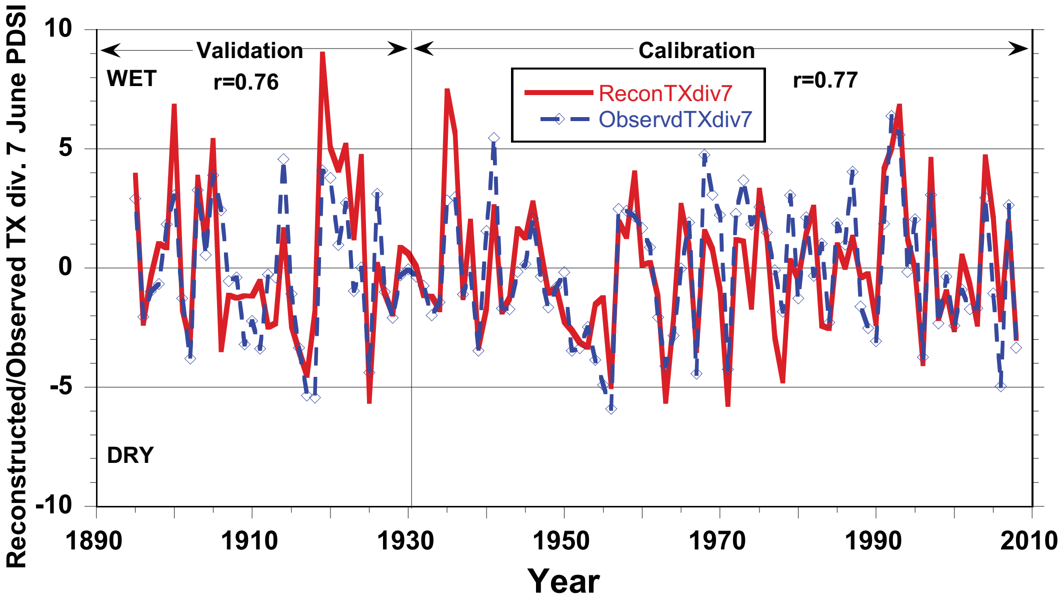

Fig. 4. Climate division 7 (S. Central) June PDSI reconstructed (solid line) and observed (dashed line) series 1895–2008 (Fig. 1, Table A6). $R^2 = 0.595$.

The results show that the February–May or February–June precipitation is best correlated with tree growth in the 4 divisions. Temperatures generally correlate negatively with tree growth but not nearly as strongly as the positive correlation of precipitation. June and July PDSI correlate positively with tree growth even more strongly than precipitation, and June PDSI is usually better correlated. Therefore, we chose to reconstruct June PDSI, which has been used to reconstruct divisional Texas climate previously (Stahle and Cleaveland 1988).

We created climate reconstructions with the program, PCREG (Cook et al. 1996, 1999; LDEO website 2011). PCREG is a complicated program that performs many operations to calibrate a reconstruction and validate that reconstruction against independent climatic data not used in the calibration (Snee 1977). PCREG uses principal components analysis (PCA) (Cooley and Lohnes 1971) to make new tree-

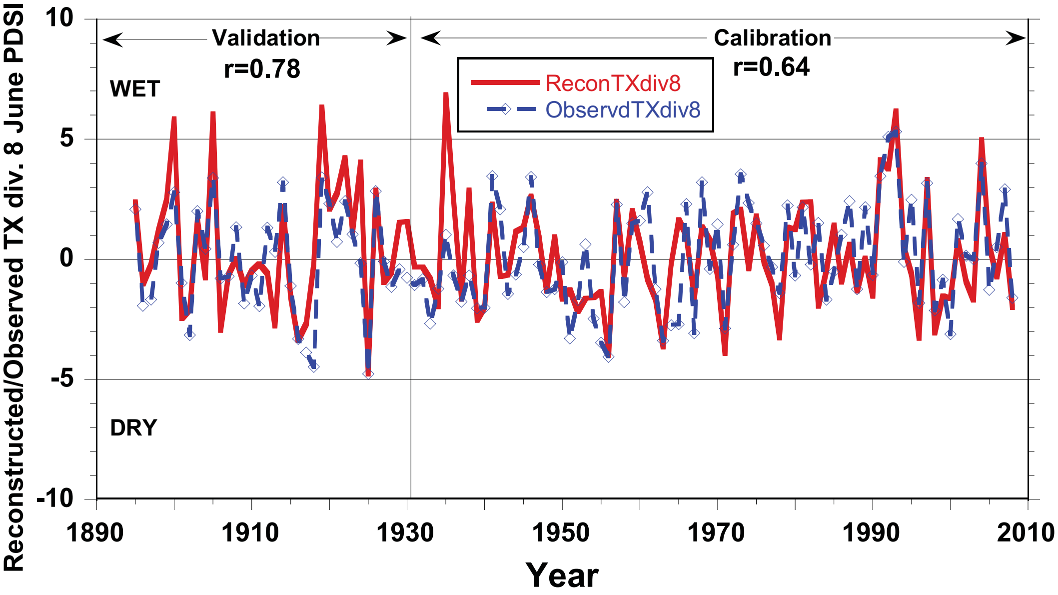

Fig. 5. Climate division 8 (Upper Coast) June PDSI reconstructed (solid line) and observed (dashed line) series 1895–2008 (Fig. 1, Table A8). $R^2 = 0.416$.

ring variables that maximize the common climate variance and do not correlate with each other. See item 2 in the appendix for further details on PCREG reconstructions.

We did 2 "nested" reconstructions of a single variable (Cook et al. 1999) to make the best use of available tree-ring data (see item 2 in the appendix where we discuss the advantages of this approach and analyze the results). We analyzed the reconstructions for the 20 driest single and multiple consecutive 2-, 3-, 4-, 5-, 6-, 7-, and 10-year droughts, the 10 driest 15- and 20-year droughts, and the 5 driest 30-year droughts, eliminating all periods with overlapping intervals. Although the longest period of consecutive drought years analyzed was 30 years, the reconstructions indicate that there may have been droughts of even longer duration in the past.

RESULTS AND DISCUSSION

The new chronology characteristics are shown in Table A2. In general, high mean sensitivity (MS; a measure of year-to-year variability), high standard deviation (SD; a measure of overall variability), and low serial correlation (r_{-1}; a measure of persistence from year-to-year in the series) are considered favorable characteristics linked to climate sensitivity (Fritts 2001; Speer 2010). Generally, the larger the sample size, the better although sample size does not by any means guarantee sensitivity to climatic influence. The San Bernard River (SBP) chronology seems the best by the first 3 criteria (MS=0.418, SD=0.409, r_{-1}=0.235) and Krause Springs (KSS) the worst (MS=0.225, SD=0.243, r_{-1}=0.422) although KSS is the best

Table 1. Analysis of error in reconstruction of 1974 June PDSI in Texas climate divisions 5 (Trans Pecos), 6 (Edwards Plateau), 7 (S. Central), and 8 (Upper Coast).

	Divisions			
	5	6	7	8
Observed June PDSI	-3.09	-2.98	1.83	2.35
Reconstructed June PDSI	-7.52	-5.54	-1.66	-0.39
Residual	-4.43	-2.56	-3.49	-2.74
Residual % of Observed	143.3%	85.9%	190.7%	116.6%
Observed Rank (1895-2008)	12	18	78	95
Reconstructed Rank (1895-2008)	1	2	37	55

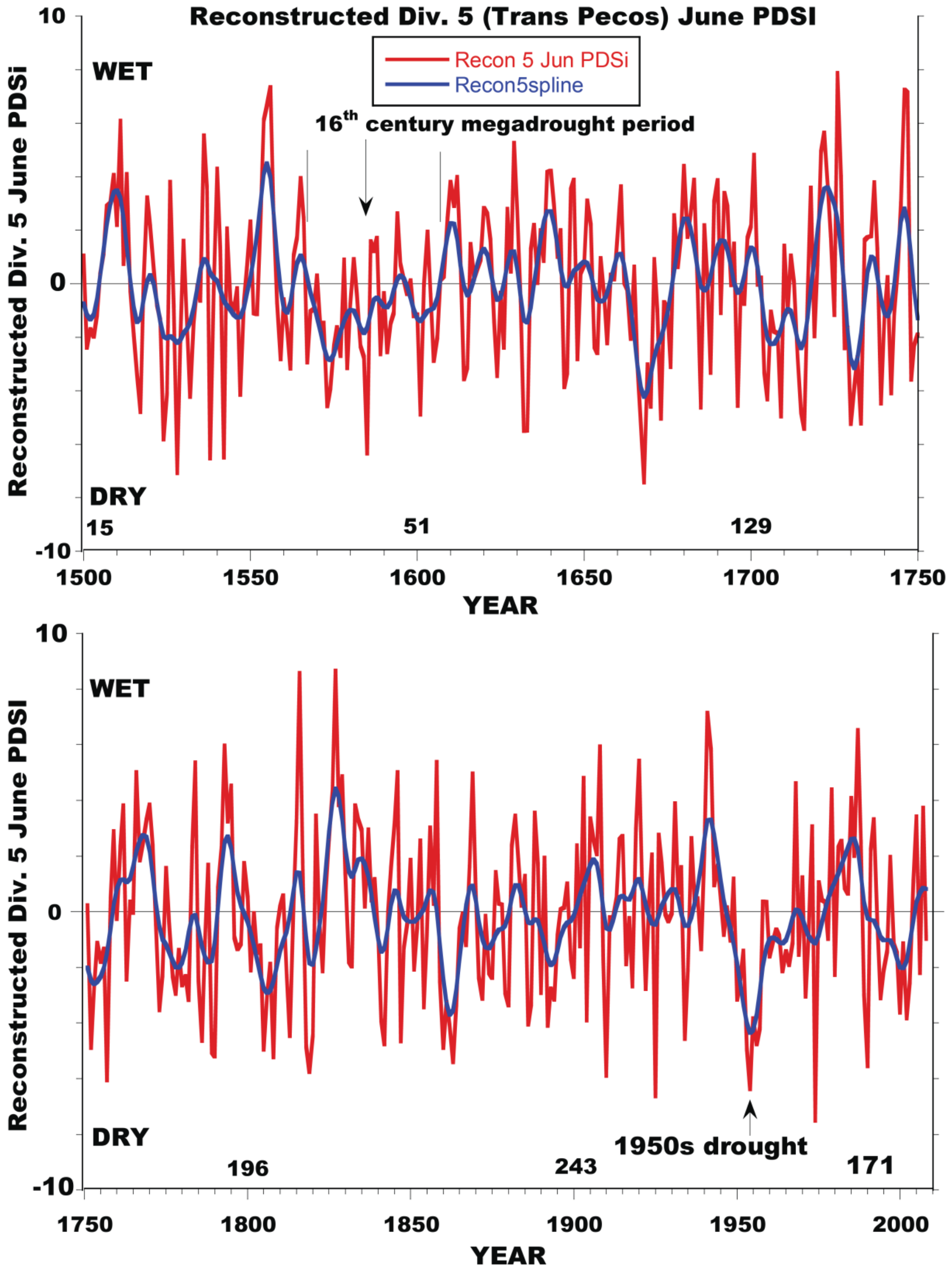

Fig. 6. . Climate division 5 (Trans Pecos) June PDSI reconstruction 1500–2008 based on 2 baldcypress and 2 Douglas-fir chronologies (Fig. 1). The blue line is a cubic spline fitted with parameters that would reduce the amplitude of a 10-year sine wave by 50% (Cook and Peters 1981). Numbers along bottom of plot are the number of radii at that time. The 1500s megadrought and 1950s drought periods are indicated. The megadrought period conditions do not appear as severe as those that are known to have occurred farther west (Stahle et al. 2000, 2007; Cook et al. 2010).

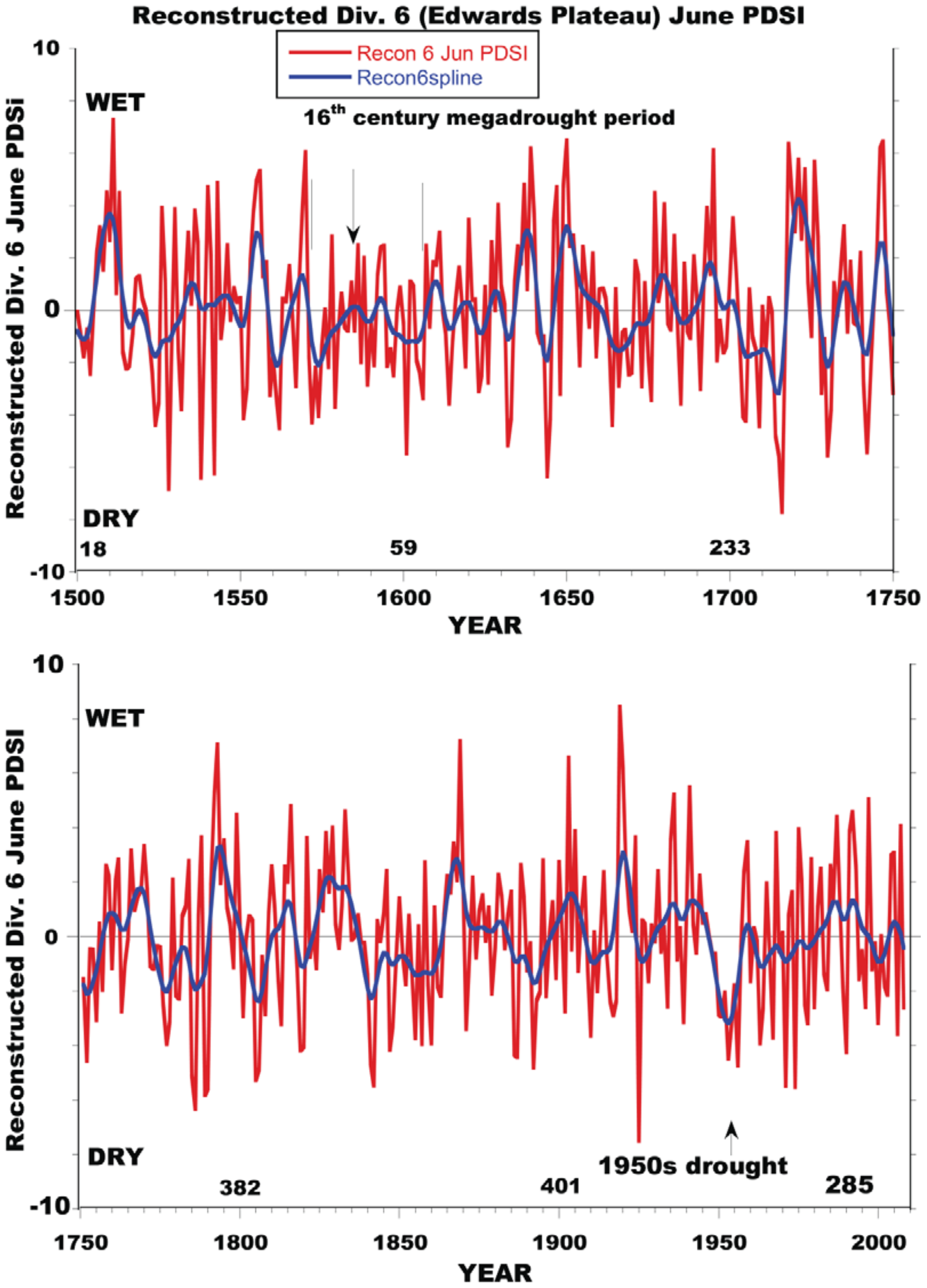

Fig. 7. Climate division 6 (Edwards Plateau) June PDSI reconstruction 1500–2008 (1648–2008 based on 3 baldcypress, 2 Douglas-fir, and a regional composite post oak chronology; 1500–1647 based on the above, without the post oak chronology; Figs. 1 and A1, Tables A4 and A5). The blue line is a cubic spline fitted with parameters that would reduce the amplitude of a 10-year sine wave by 50% (Cook and Peters 1981). Numbers along bottom of plot are number of radii at that time. The 1500s megadrought and 1950s drought periods are indicated. Neither the megadrought nor the 1950s drought conditions appear as severe as those that occurred in division 5 farther west.

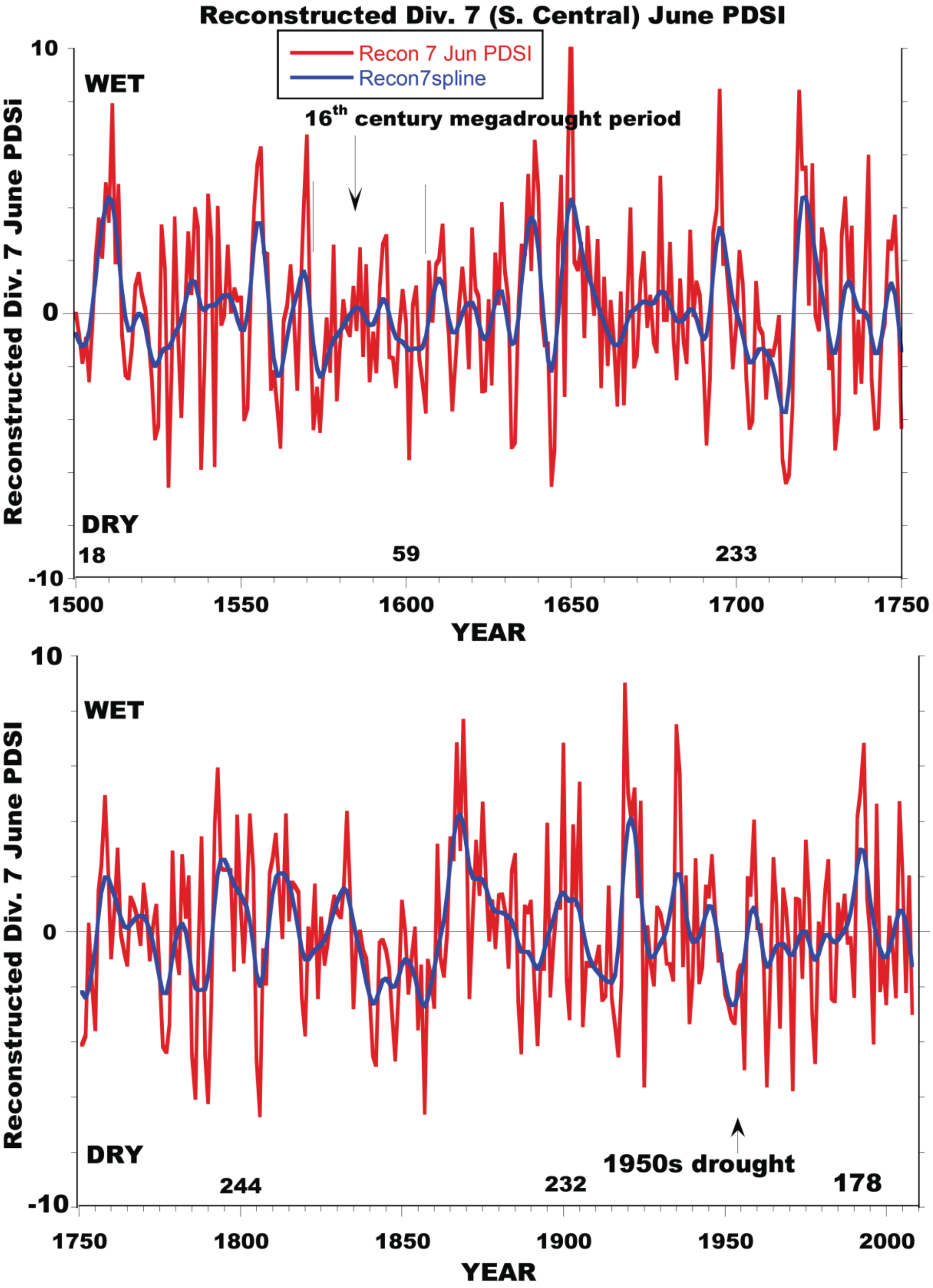

Fig. 8. Climate division 7 (S. Central) June PDSI reconstruction 1500–2008 (1648–2008 based on 3 baldcypress and a regional composite post oak chronology; 1500–1647 based on the 3 baldcypress and 2 Douglas-fir chronologies; Figs. 1 and A2, Tables A6 and A7). The blue line is a cubic spline fitted with parameters that would reduce the amplitude of a 10-year sine wave by 50% (Cook and Peters 1981). Numbers along bottom of plot are number of radii at that time. The 1500s megadrought and 1950s drought periods are indicated. Neither the megadrought nor the 1950s drought conditions appear as severe as those that occurred in divisions 5 or 6 farther west.

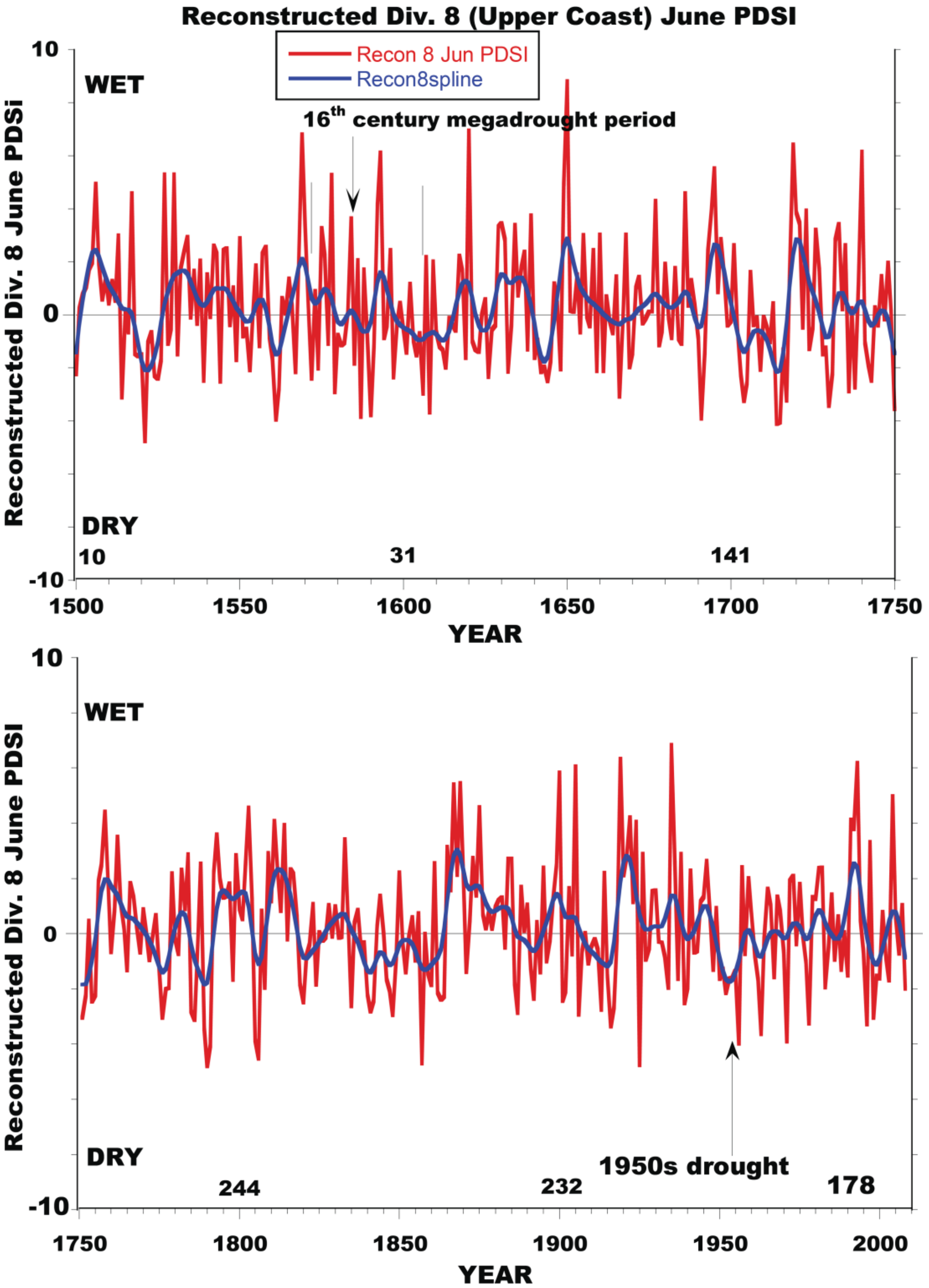

Fig.9. Climate division 8 (Upper Coast) June PDSI reconstruction 1500–2008 (1648–2008 based on 3 baldcypress and a regional composite post oak chronology; 1500–1647 based on the 3 baldcypress chronologies; Figs. 1 and A3, Tables A8 and A9). The blue line is a cubic spline fitted with parameters that would reduce the amplitude of a 10-year sine wave by 50% (Cook and Peters 1981). Numbers along bottom of plot are number of radii at that time. The 1500s megadrought and 1950s drought periods are indicated. The megadrought effects have apparently disappeared and the 1950s drought appears much less severe than is seen in the climate divisions to the west.

Table 2. Climate division 5 (Trans Pecos) June PDSI, 1500–2008 reconstructed droughts of 1-7 and 10-year lengths in order of severity. Overlaps between time periods in a column have been eliminated.

Case	Single Year	2 Year Avg	3 Year Avg	4 Yr/Avg	5 Yr/Avg	6 Yr/Avg	7 Yr/Avg	10 Yr/ Avg
1 Driest	1974* -7.52	1667–68 -6.39	1666–68 -5.26	1667–70 -5.10	1953–57 -4.82	1952–57 -4.25	1951–57 -3.99	1948–57 -3.10
2	1668 -7.44	1953–54 -5.66	1953–55 -5.05	1953–56 -4.98	1666–70 -4.68	1859–64 -3.91	1667–73 -3.64	1667–76 -3.02
3	1528 -7.08	1632–33 -5.50	1818–20 -5.01	1860–63 -4.41	1860–64 -4.20	1665–70 -3.79	1859–65 -3.45	1748–57 -2.54
4	1925 -6.64	1818–19 -5.30	1714–16 -4.30	1730–33 -4.26	1729–33 -3.74	1728–33 -3.51	1728–34 -2.78	1859–68 -2.38
5	1538 -6.54	1789–90 -5.12	1862–64 -4.28	1805–08 -3.76	1804–08 -3.25	1752–57 -2.99	1571–77 -2.63	1804–13 -2.29
6	1542 -6.50	1715–16 -5.10	1730–32 -3.94	1817–20 -3.31	1573–77 -3.03	1803–08 -2.96	1803–09 -2.62	1524–33 -2.18
7	1954 -6.38	1524–25 -4.97	1631–33 -3.88	1714–17 -3.27	1786–90 -2.82	1704–09 -2.88	1751–57 -2.53	1571–80 -2.14
8	1585 -6.36	1862–63 -4.74	1583–85 -3.82	1573–76 -3.11	1524–28 -2.81	1572–77 -2.77	1523–29 -2.51	1707–16 -2.00
9	1757 -6.07	1528–29 -4.62	1523–25 -3.77	1522–25 -3.02	1705–09 -2.79	1785–90 -2.76	1703–09 -2.43	1773–82 -1.94
10	1910 -5.90	1584–85 -4.56	1573–75 -3.61	1582–85 -2.97	1713–17 -2.61	1524–29 -2.70	1785–91 -2.24	1994–2003 -1.85
11	1524 -5.82	1730–31 -4.54	1859–61 -3.55	2000–03 -2.78	1753–57 -2.60	1528–33 -2.47	1776–82 -2.17	1871–80 -1.45
12	1819 -5.76	1956–57 -4.48	1515–17 -3.36	1892–95 -2.72	1999–2003 -2.52	1777–82 -2.46	1579–85 -2.13	1886–95 -1.40
13	1990 -5.55	1841–42 -4.34	1806–08 -3.36	1752–55 -2.63	1778–82 -2.50	1818–23 -2.33	1818–24 -1.88	1583–92 -1.39
14	1632 -5.51	1989–90 -4.27	1527–29 -3.35	1704–07 -2.61	1748–52 -2.48	1998–2003 -2.30	1711–17 -1.86	1728–37 -1.21
15	1633 -5.49	1573–74 -4.25	1892–94 -3.34	1631–34 -2.59	1818–22 -2.36	1711–16 -2.14	1998–2004 -1.82	1891–1900 -1.17
16	1716 -5.42	1516–17 -4.08	1840–42 -3.17	1514–1517 -2.59	1777–81 -2.32	1890–95 -1.98	1890–96 -1.69	1538–47 -1.17
17	1863 -5.41	1860–61 -4.07	1789–91 -3.13	1673–76 -2.45	1785–89 -2.27	1808–13 -1.98	1542–48 -1.60	1597–1606 -1.10
18	1667 -5.33	1732–33 -3.99	1755–57 -3.06	1739–42 -2.39	1890–94 -2.20	1580–85 -1.96	1784–90 -1.60	1958–67 -1.01
19	1730 -5.24	1805–06 -3.97	1817–19 -2.93	1840–43 -2.38	1581–85 -2.19	1956–61 -1.82	1960–66 -1.38	1969–78 -0.78
20	1808 -5.24	1527–28 -3.96	1752–54 -2.91	1779–82 -2.38	1672–76 -2.15	1542–47 -1.75	1600–06 -1.35	1853–62 -0.76

*June PDSI estimates for 1974 had a large amount of error, and were consistently more negative in all 4 divisions reconstructed than the observed values. See discussion of estimation error in general and for 1974 in particular on pages 68–71.

replicated and SBP the least replicated (Table A2c). The performance of these 3 chronologies in the PCA and regression analyses with climate (Tables A3-A9) confirms the apparent ranking in usefulness for climate reconstruction based on chronology statistics.

Site conditions of the new chronologies varied consider-

Table 3. Climate division 6 (Edwards Plateau) June PDSI, 1500–2008 reconstructed droughts of 1-7 and 10-year lengths in order of severity. Overlaps between time periods in a column have been eliminated.

Case	Single Year	2 Year Avg	3 Year Avg	4 Yr / Avg	5 Yr / Avg	6 Yr / Avg	7 Yr / Avg	10 Yr / Avg
1 Driest	1716 -7.71	1715–16 -6.64	1714–16 -6.02	1714–17 -4.67	1713–17 -3.75	1951–56 -3.21	1950–56 -3.16	1707–16 -2.60
2	1925 -7.51	1785–86 -5.72	1840–42 -3.86	1953–56 -3.57	1952–56 -3.26	1711–16 -3.20	1711–17 -2.83	1948–57 -2.38
3	1528 -6.84	1789–90 -5.70	1643–45 -3.82	1805–08 -3.44	1571–75 -2.73	1785–90 -3.07	1785–91 -2.35	1571–80 -1.75
4	1538 -6.40	1644–45 -5.24	1741–43 -3.70	1728–31 -3.39	1641–45 -2.71	1704–09 -2.40	1571–77 -2.25	1777–86 -1.62
5	1644 -6.35	1805–06 -5.08	1805–07 -3.63	1559–62 -3.23	1786–90 -2.66	1572–77 -2.33	1703–09 -2.24	1840–49 -1.62
6	1786 -6.34	1841–42 -5.08	1785–87 -3.55	1642–45 -3.18	1804–08 -2.63	1750–55 -2.21	1749–55 -1.96	1854–63 -1.49
7	1542 -6.24	1730–31 -4.67	1572–74 -3.51	1571–74 -3.08	1728–32 -2.50	1728–33 -2.12	1523–29 -1.88	1523–32 -1.46
8	1789 -5.82	1632–33 -4.65	1729–31 -3.47	1839–42 -2.95	1559–63 -2.49	1803–08 -2.07	1664–70 -1.84	1748–57 -1.45
9	1790/ -5.57	1886–87 -4.39	1523–25 -3.44	1522–25 -2.81	1838–42 -2.41	1559–64 -2.03	1772–78 -1.80	1800–09 -1.42
10	1715 -5.56	1742–43 -4.18	1954–56 -3.26	1741–44 -2.76	1521–25 -2.25	1523–28 -2.02	1801–07 -1.79	1885–94 -1.38
11	1730/ -5.56	1704–05 -4.13	1560–62 -3.22	1775–78 -2.49	1890–94 -2.15	1776–81 -1.98	1854–60 -1.71	1597–1606 -1.32
12	1974 -5.54	1819–20 -4.12	1776–78 -3.18	1749–52 -2.44	1705–09 -2.08	1838–43 -1.91	1838–44 -1.66	1559–68 -1.27
13	1971 -5.50	1524–25 -3.96	1703–05 -3.18	1891–94 -2.37	1774–78 -2.06	1601–06 -1.85	1600–06 -1.66	1664–73 -1.26
14	1601/ -5.48	1528–29 -3.95	1789–91 -3.16	1854–57 -2.25	1750–54 -2.04	1664–69 -1.75	1886–92 -1.58	1909–18 -1.24
15	1842/ -5.48	1561–62 -3.93	1818–20 -3.16	1703–06 -2.18	1739–43 -1.90	1855–60 -1.72	1728–34 -1.57	1962–71 -1.12
16	1742 -5.44	1953–54 -3.88	1750–52 -3.09	1971–74 -2.16	1528–32 -1.87	1641–46 -1.69	1559–65 -1.49	1696–1705 -0.88
17	1805 -5.28	1847–48 -3.75	1892–94 -3.08	1817–20 -2.12	1666–70 -1.87	1738–43 -1.66	1738–44 -1.41	1850–59 -0.83
18	1632/ -5.18	1538–39 -3.72	1631–33 -3.04	1949–52 -2.12	1963–67 -1.78	1889–94 -1.55	1961–67 -1.25	1925–34 -0.82
19	1785 -5.11	1892–93 -3.59	1847–49 -2.74	1915–18 -2.07	1859–63 -1.73	1847–52 -1.55	1642–48 -1.12	1994–2003 -0.83
20	1806 -4.87	1551–52 -3.55	1950–52 -2.62	1630–33 -2.05	1970–74 -1.70	1962–67 -1.52	1912–18 -1.10	1736–45 -0.70

ably. The Guadalupe River State Park (GRP) and SBP sites are confined to river banks with relatively minor human disturbance. The KSS site contains a long-established commercial park with considerable human disturbance, including bulldozer work, soil compaction by heavy human traffic, extensive modifications to the original hydrology, and anthropogenic damage to the trees. In addition, the KSS trees grow in a wide variety of hydrologic micro-sites, far more variable than the

Table 4. Climate division 7 (South Central) June PDSI, 1500–2008 reconstructed droughts of 1-7 and 10-year lengths in order of severity. Overlaps between time periods in a column have been eliminated.

Case	SingleYear	2 Year Avg	3 YearAvg	4 Yr / Avg	5 Yr / Avg	6 Yr / Avg	7 Yr / Avg	10 Yr / Avg
1 Driest	1806 -6.67	1715–16 -6.22	1714–16 -5.98	1714–17 -5.36	1713–17 -4.31	1712–17 -3.77	1711–17 -3.45	1708–17 -2.95
2	1857 -6.58	1644–45 -5.78	1789–91 -4.44	1642–45 -3.47	1571–75 -2.85	1785–90 -3.03	1785–91 -2.98	1840–49 -2.43
3	1528 -6.50	1805–06 -5.64	1643–45 -4.23	1805–08 -3.46	1952–56 -2.84	1750–55 -2.88	1950–56 -2.72	1947–56 -2.02
4	1644 -6.46	1789–90 -5.33	1750–52 -4.06	1559–62 -3.43	1855–59 -2.81	1951–56 -2.80	1854–60 -2.38	1851–60 -1.99
5	1715 -6.37	1785–86 -5.22	1805–07 -3.98	1775–78 -3.42	1559–63 -2.80	1855–60 -2.79	1571–77 -2.38	1571–80 -1.87
6	1790 -6.19	1632–33 -4.95	1776–78 -3.97	1572–75 -3.40	1641–45 -2.78	1572–77 -2.66	1749–55 -2.35	1909–18 -1.83
7	1716 -6.06	1841–42 -4.65	1840–42 -3.92	1839–42 -3.19	1786–90 -2.75	1838–43 -2.31	1912–18 -2.20	1523–32 -1.62
8	1786 -6.03	1524–25 -4.47	1572–74 -3.86	1855–58 -3.10	1750–54 -2.74	1559–64 -2.28	1842–48 -2.18	1782–91 -1.56
9	1538 -5.82	1730–31 -4.44	1523–25 -3.81	1728–31 -3.09	1838–42 -2.69	1912–17 -2.26	1523–29 -2.14	1597–1606 -1.48
10	1542 -5.73	1561–62 -4.33	1855–57 -3.78	1522–25 -3.06	1774–78 -2.54	1523–28 -2.16	1703–09 -2.02	1559–1568 -1.41
11	1971 -5.73	1742–43 -4.32	1741–43 -3.69	1915–18 -3.06	1741–45 -2.47	1773–78 -2.07	1772–78 -1.92	1962–71 -1.32
12	1925 -5.58	1776–77 -4.27	1785–87 -3.63	1840–43 -3.04	1521–25 -2.42	1601–06 -2.03	1600–06 -1.78	1772–81 -1.28
13	1963 -5.58	1528–29 -4.27	1560–62 -3.62	1741–44 -2.99	1845–49 -2.36	1704–09 -1.94	1559–65 -1.70	1925–34 -1.09
14	1714 -5.52	1750–51 -4.20	1703–05 -3.60	1750–53 -2.98	1805–09 -2.35	1641–46 -1.88	1835–41 -1.65	1736–45 -1.06
15	1601 -5.46	1704–05 -4.17	1915–17 -3.46	1950–53 -2.83	1913–17 -2.21	1845–50 -1.78	1886–92 -1.47	1885–94 -1.00
16	1645 -5.10	1916–17 -3.98	1729–31 -3.42	1846–49 -2.78	1749–53 -2.21	1741–46 -1.60	1748–54 -1.31	1748–57 -0.89
17	1730 -5.10	1856–57 -3.92	1847–49 -3.27	1788–91 -2.49	1703–07 -2.03	1804–09 -1.59	1642–48 -1.31	1819–28 -0.80
18	1632 -5.04	1538–39 -3.87	1841–43 -3.24	1702–05 -2.43	1727–31 -2.00	1962–67 -1.47	1961–67 -1.23	1977–86 -0.77
19	1562 -5.03	1847–48 -3.86	1632–34 -3.18	1631–34 -2.26	1528–32 -1.94	1705–10 -1.45	1661–67 -1.14	1661–70 -0.76
20	1956 -4.97	1963–64 -3.86	1690–92 -3.10	1784–87 -2.23	1960–64 -1.72	1906–11 -1.45	1725–31 -1.06	1994–2003 -0.65

other sites. Some of the KSS trees grow on the stream banks with their roots in the water, while others grow on the valley slopes at considerably higher elevations, far away from the stream, where they must depend on soil moisture to sustain growth. These heterogeneous site conditions may account for the relatively weak climate signal at the KSS site compared to the less disturbed and hydrologically more homogeneous GRP and SBP sites.

Table 5. Climate division 8 (Upper Coast) June PDSI, 1500–2008 reconstructed droughts of 1-7 and 10-year lengths in order of severity. Overlaps between time periods in a column have been eliminated.

Case	Single Year	2 Year Avg	3 YearAvg	4 Yr/Avg	5 Yr/Avg	6 Yr/Avg	7 Yr/Avg	10 Yr/Avg
1 Worst	1790 -4.81	1790–91 -4.43	1789–91 -4.11	1714–17 -3.18	1713–17 -2.46	1786–91 -2.23	1785–91 -2.31	1708–17 -1.60
2	1925 -4.77	1805–06 -4.19	1714–16 -3.16	1789–92 -2.52	1521–25 -2.23	1712–17 -2.22	1520–26 -2.05	1840–49 -1.34
3	1521 -4.76	1714–15 -4.09	1750–52 -2.95	1805–08 -2.38	1750–54 -2.17	1750–55 -2.18	1711–17 -1.97	1947–56 -1.31
4	1857 -4.71	1561–62 -3.37	1560–62 -2.79	1518–21 -2.32	1952–56 -2.14	1521–26 -2.15	1950–56 -1.95	1517–26 -1.28
5	1806 -4.53	1750–51 -3.31	1703–05 -2.70	1559–62 2.30	1787–91 -2.04	1951–56 -2.00	1749–55 -1.85	1855–64 -1.25
6	1714 -4.12	1520–21 -3.12	1519–21 -2.60	1749–52 -2.19	1751–55 -1.90	1640–45 -1.82	1857–63 -1.43	1909–18 -1.07
7	1715 -4.06	1916–17 -3.03	1915–17 -2.52	1702–05 -2.15	1641–45 -1.86	1912–17 -1.45	1640–46 -1.39	1783–92 -1.02
8	1791 -4.05	1785–86 -2.98	1805–07 -2.51	1953–56 -2.14	1559–63 -1.71	1559–64 -1.42	1703–09 -1.29	1604–13 -0.98
9	1956 -4.00	1704–05 -2.91	1840–42 -2.49	1775–78 -2.11	1838–42 -1.66	1855–60 -1.38	1912–18 -1.28	1746–55 -0.97
10	1561 -3.95	1730–31 -2.83	1776–78 -2.34	1728–31 -2.10	1804–08 -1.65	1641–46 -1.35	1772–78 -1.25	1769–78 -0.85
11	1691 -3.93	1691–92 -2.68	1954–56 -2.31	1642–45 -2.09	1913–17 -1.63	1838–43 -1.34	1586–91 -1.10	1994–2003 -0.81
12	1971 -3.91	1955–56 -2.67	1729–31 -2.29	1857–60 -2.01	1587–91 -1.58	1998–2003 -1.34	1840–46 -1.07	1639–48 -0.76
13	1587 -3.86	1962–63 -2.65	1862–64 -2.27	1915–18 -1.95	1774–78 -1.55	1773–78 -1.30	1559–65 -1.02	1559–68 -0.72
14	1805 -3.85	1841–42 -2.63	1846–48 -2.23	1839–42 -1.95	1845–49 -1.52	1603–08 -1.28	1600–06 -1.00	1962–71 -0.68
15	1590 -3.79	1776–77 -2.53	1642–44 -2.21	1846-49 -1.90	1856–60 -1.46	1702–07 -1.23	1608–14 -0.99	1818–27 -0.60
16	1608 -3.69	1847–48 -2.51	1559–61 -2.14	1523–26 -1.77	1702–06 -1.39	1585–90 -1.09	1994–2000 -0.90	1581–90 -0.50
17	1963 -3.64	1590–91 -2.47	1524–26 -2.14	1587–90 -1.68	1604–08 -1.34	1560–65 -1.05	1819–25 -0.89	1661–70 -0.46
18	1750 -3.55	1524–25 -2.36	1785–87 -2.13	1522–25 -1.60	1727–31 -1.33	1819–24 -1.05	1621–27 -0.86	1886–95 -0.40
19	1789 -3.46	1857–58 -2.36	1690–92 -2.08	1961–64 -1.57	1998–2002 -1.26	1844–49 -1.03	1847–53 -0.80	1698–07 -0.40
20	1730 -3.44	1754–55 -2.35	1998–2000 -2.07	1603–06 -1.54	1579–83 -1.16	1610–15 -0.94	1886–92 -0.78	1925–34 -0.36

The nature and amount of error in the reconstructions deserve consideration. Figs. 2-5 show that very few of the reconstructed PDSI values match the observations exactly. The basic regression equation contains an error term (Draper and Smith 1981) to account for the imperfect relationship between the climate and tree growth variables. Because the new variables created by PCA of the tree-ring chronologies calibrate less than 100% of the climate variance, some amount

Table 6. Average June PDSI reconstructed drought for non-overlapping periods of 15, 20, and 30 consecutive years from Texas climate divisions 5-8, 1500–2008. The driest10 periods are shown for 15- and 20-year periods, but only five 30-year periods are shown because it is difficult to get 10 non-overlapping 30-year periods of drought.

A. Division 5

Case	15-Year Period	Avg June PDSI		20-Year Period	Avg June PDSI		30-Year Period	Avg June PDSI
1	1951–65	-2.29		1950–69	-1.86		1949–78	-1.63
2	1571–85	-1.98		1572–91	-1.72		1568–97	-1.29
3	1662–76	-1.88		1860–79	-1.71		1728–57	-1.07
4	1703–17	-1.79		1654–73	-1.53		1517–46	-1.03
5	1515–29	-1.73		1801–20	-1.37		1797–1826	-0.96
6	1861–75	-1.68		1517–36	-1.26			
7	1799–1813	-1.59		1697–1716	-1.22			
8	1522–36	-1.49		1772–91	-1.16			
9	1777–91	-1.39		1738–57	-1.01			
10	1730–44	-1.34		1668–87	-0.90			

B. Division 6

Case	15-Year Period	Avg June PDSI		20-Year Period	Avg June PDSI		30-Year Period	Avg June PDSI
1	1703–17	-2.20		1697–1716	-1.74		1949–78	-1.24
2	1776–90	-1.59		1841–60	-1.49		1837–66	-0.89
3	1841–55	-1.51		1950–69	-1.40		1573–1602	-0.81
4	1950–64	-1.48		1560–79	-1.16		1688–1717	-0.79
5	1515–29	-1.29		1772–91	-1.14		1728–57	-0.68
6	1729–43	-1.10		1801–20	-0.86			
7	1806–20	-1.06		1738–57	-0.72			
8	1572–86	-1.04		1513–32	-0.67			
9	1884–98	-0.95		1870–89	-0.66			
10	1662–76	-0.90		1657–76	-0.60			

C. Division 7

Case	15-Year Period	Avg June PDSI		20-Year Period	Avg June PDSI		30-Year Period	Avg June PDSI
1	1703–17	-2.54		1841–60	-2.21		1835–64	-1.53
2	1846–60	-2.11		1698–1717	-1.80		1949–78	-1.02
3	1777–91	-1.68		1773–92	-1.36		1573–1602	-0.89
4	1742–56	-1.41		1561–80	-1.30		1688–1717	-0.88

Table 6 (continued)

5	1515–29	-1.37		1948–67	-1.17		1763–92	-0.72
6	1950–64	-1.31		1737–56	-0.98			
7	1561–75	-1.11		1703–22	-0.72			
8	1903–17	-0.94		1590–1609	-0.72			
9	1590–1604	-0.91		1514–33	-0.65			
10	1971–85	-0.83		1971–90	-0.52			

Division 8

Case	15-Year Period	Avg June PDSI		20-Year Period	Avg June PDSI		30-Year Period	Avg June PDSI
1	1703–17	-1.53		1841–60	-1.15		1835–64	-0.90
2	1846–60	-1.14		1699–1718	-0.92		1949–78	-0.58
3	1777–91	-1.00		1773–92	-0.88		1598–1627	-0.47
4	1742–56	-0.99		1948–67	-0.82		1702–31	-0.36
5	1949–63	-0.94		1598–1617	-0.75		1763–92	-0.35
6	1598–1612	-0.87		1737–56	-0.64			
7	1513–27	-0.82		1548–67	-0.36			
8	1903–17	-0.57		1508–27	-0.33			
9	1553–67	-0.55		1605–24	-0.26			
10	1829–43	-0.47		1821–40	-0.22			

of reconstruction error is inevitable. At present, unfortunately, there is no universally accepted way to put confidence limits on the reconstructions.

One factor that influences reconstruction error is replication, that is the variable number of radii in the chronologies through time. Replication diminishes as the number of relatively young samples decreases. This is a reason for beginning the analyses of reconstructions at 1500 although all the baldcypress and Douglas-fir chronologies begin earlier (Tables A1, A2a). This diminished replication tends to inflate variance, which is the reason we detrended the variance when creating chronologies. The number of radii at 1500, 1600, 1700, 1800, 1900, and 1990 are shown along the bottom of the X-axis of Figs. 6–9. In the division 5 reconstruction, for example, replication ranges from a minimum of 15 at 1500, to a maximum of 243 at 1900 (Fig. 6). The degree of replication in the earliest part of these reconstructions is judged to be acceptable, but the amount of error in the estimates necessarily increases as sample size diminishes. In the division 6 reconstruction (Fig. 7) the largest sample size was 401 at 1900, which far exceeds the replication in many tree-ring studies. The number of trees in each chronology is shown in Tables A1 and A2.

An example of a large amount of error in a single year is the reconstruction of 1974. For some reason, the degree of drought was overestimated in all divisional reconstructions, that is, soil moisture conditions must have consistently decreased tree growth more than the observed PDSI would indicate (Table 1). Since the positive and negative deviations from the regression estimates were tested and found to be consistently random (Tables A3–A9), and are constrained to sum to 0.0 in the calibration (Draper and Smith 1981), there should be no systematic errors over the period of calibration, 1931–2008. Errors of the type encountered in 1974, where the PDSI is overestimated, must be balanced by underestimation of other years. The instrumental PDSI rankings of 1974 (12, 18, 78, and 95) in the 1895–2008 period become wetter from west to east, as do the rankings (1, 2, 37, and 55) of 1974 reconstructed PDSI in the 1895–2008 period (Table 1). This shows that the estimates follow the observed climate trend, albeit with considerable error. We cannot explain an error reconstructing a year that seems to be consistent in direction over all the reconstructions, but the error may be created by some inadequacy in the PDSI soil moisture model, which was created for measurement of the effects of drought on row crops, not trees (Palmer 1965).

The worst extended drought in the instrumental climatic data appears to be what is referred to as the 1950s drought. These data show that the 1950s drought actually may have begun in 1948 or even 1947, because 1947, 1948, and 1949 are below average in some of the divisional data (Table A11). We analyzed and compared the reconstructed drought series through time (below) to gauge the relative severity of the 1950s drought. Although the Dust Bowl drought of the 1930s was the overall worst experienced nationally during the 20th century (Cook et al. 1996, 1999), the worst effects in Texas occurred north of our area of reconstruction.

Tables 2 to 5 summarize the 20 worst droughts in the 4 climate divisions over different intervals ranging from a single year to 7 consecutive years, and finally, 10 consecutive years, 1500–2008. We systematically excluded intervals that overlapped, i.e., had 1 or more years in common with other intervals from these tables, and this led to rejecting many possible droughts, especially in the decadal category. For example, in division 5, 145 ranked combinations had to be considered before the 20 in Table 2 could be tallied, so that 125 combinations of 10 consecutive years with overlapping intervals had to be rejected. This shows that drought occurs randomly and sporadically but is concentrated in certain periods and may be a decade or more in length.

The 1950s drought is among the worst, but droughts as bad or worse have occurred in other periods. Table 4 (S. Central, div. 7) shows that the early 1700s dominate the top rankings in that division, with 3 years (1714, 1715, 1716) in the single year category ranking among the most severe and all other time periods of the early 1700s worst in all other categories. Certain periods have experienced long and severe periods of drought, while other periods have been spared. Among these periods of anomalous drought, in rough order of severity from all climate divisions (because the order differs from division to division) are the early 1700s, the mid-1800s (1840–1863), the 1950s (1947–1957), and the 1500s (1571–1580, 1523–1532, 1559–1568, 1581–1590, 1597–1606), the early 1900s (1909–1918, 1925–1934), the late 1700s (1777–1792), the late 20th century (1962–1971, 1977–1986, 1994–2003). Bad droughts clearly recur time after time in these 4 Texas climate divisions.

There are clear differences among the climate divisions. For example, while division 7 has the early 1700s as driest in all categories, the other divisions show more variability. These reconstructions also appear to confirm other reconstructions created using different chronologies (Cook et al. 1996, 1999; Stahle et al. 2000, 2007), e.g., division 5 (Table 2) has five 10-year periods in the 16th and early 17th century (in order of decreasing severity, 1524–1533, 1571–1580, 1583–1592, 1538–1547, 1597–1606). Some of those droughts occur in the period identified as the 1500s megadrought (Stahle et al. 2000, 2007; Cook et al. 2004). The 16th century megadrought appears most clearly in division 5 (Fig. 6), although megadrought conditions were much worse in the region west of Texas (Stahle et al. 2000, 2007). It becomes less pronounced farther east in divisions 6 and 7 (Figs. 7, 8), disappearing almost completely in division 8, the wettest division (Table A2a; Table 5; Fig. 9). The same diminution in severity from west to east also holds true for the 1950s drought (Figs. 2–9, Tables 2–5).

Decadal-length droughts seem to be distributed fairly equally, with one exception. The 1600s appears to have notably fewer droughts of that duration than the other 4 centuries. This appears to be a real phenomenon, another instance of long-term climate variability.

Many of the 10-year droughts reconstructed actually were part of longer drought regimes, e.g., 1772–1781 and 1782–1791, and 1559–1568 and 1571–1580 in division 7 and 1840–1849 and 1854–1863 in division 6. We investigated droughts 15-, 20-, and 30-years long (Table 6). The 1950s drought appears in each division for all 3 drought durations. In division 5 the 1950s drought is the worst at the 15-, 20-, and 30-year durations, culminating in the 1949–1978 period with a 30-year average June PDSI of -1.63. Additional 30-year periods that occurred in 2 or more of the 4 divisions were the mid- to late-1500s, early-, mid-, and late-1700s, and the early- and mid-1800s. The long duration and severity that characterizes megadroughts does not seem to be solely a 16th century phenomenon. Most of the megadroughts identified in the past (Stahle et al. 2000, 2007; Cook et al. 2009), however, appear to have been most extreme in areas west of Texas.

The reconstruction of the 20th century seems to have as many long drought episodes as other centuries (Tables 2–6). While division 5 has only four 10-year periods in the 20th century (Table 2), divisions 6 and 8 have 5 (Tables 3 and 5) and division 7 has 6 (Table 4). This, and the results with the 15-, 20-, and 30-year drought intervals, clearly indicates that, overall, the 20th century in these 4 Texas climate divisions was not anomalously wet or dry and appears typical of the 1500–2008 time period. Therefore, it can be expected that droughts as bad as or worse than the 1950s will occur in the future. A future that may very well see accelerating climate change and continuing rapid population growth does not bode well for Texas water resources (Cook et al. 2007; IPCC 2007a, b; Seager et al. 2007; Banner et al. 2010; Min et al. 2011; Pall et al. 2011).

In the future these reconstructions could be improved by collecting more baldcypress chronologies and collecting samples from historical structures, such as the San Antonio missions, to improve the early replication of existing chronologies and to extend them into the past. In addition, each annual ring is divided into 2 parts, earlywood and latewood (Panshin and de Zeeuw 1970). By measuring these separately and making separate chronologies, the growing season can be divided temporally (Therrell et al. 2002; Cleaveland et al. 2003; Stahle et al. 2009). This temporal division may allow separate intra-annual reconstructions, e.g., of spring and summer climate.

SUMMARY AND CONCLUSIONS

The June Palmer Drought Severity Index (PDSI) for climate divisions 5–8 (Trans Pecos, Edwards Plateau, South Central, and Upper Coast, respectively) was successfully reconstructed for 1500–2008. Decadal or longer droughts appear to be randomly distributed and occur frequently in the reconstructions, although the 1600s may have had fewer protracted droughts than the other 4 centuries. The reconstructions confirm that the 1950s drought was severe but also show that there have been periods when drought was more severe and/or more protracted than the 1950s and that the impact might have been considerably worse. The recurrence of severe prolonged drought in South Central Texas appears to be the norm, not the exception. It would be a questionable strategy for civil authorities to assume that the 1950s drought represents the worst-case scenario to be used for planning purposes in water resources management, at least for western and central Texas. This especially holds true when water managers consider the possible impacts of climate change, combined with a rapidly growing population and new demands on water resources. Water managers must consider intensive water conservation programs and development of new water resources (e.g., desalination of seawater) to meet these challenges (Banner et al. 2010).

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APPENDIX

CONTENTS

1. THE TRANSFORMATION OF RING WIDTHS INTO CHRONOLOGIES

We generated chronologies with program ARSTAN (Cook 1985) (LDEO website 2011). Most trees have growth trends that must be removed in order to create time series with stationary statistical properties that reflect climate influence more accurately than undetrended ring widths. This program transforms individual ring width series (in mm) with different means and nonstationary statistical properties into dimensionless indices with a mean of 1.0 and stationary statistical properties. These index series are then averaged into the ring width chronology.

For example, many trees have a trend from relatively wide rings when young to much narrower rings as they mature. In addition, competition with adjacent trees may create growth suppression and release that leads to reduction and acceleration in growth rates, respectively, during a tree's lifespan (Cook 1985; Fritts 2001; Speer 2010). If these nonclimatic influences are not minimized, it is difficult to make reliable paleoclimatic inferences from tree rings. Among the curves used, depending on the series, are a negative exponential declining to a fixed value, a flexible cubic spline (Cook and Peters 1981; Cook 1985; Cook et al. 1990), or a regression line (Draper and Smith 1981). After the curve is fitted to a series, the program divides each annual measurement by the corresponding curve value. This process transforms the measurements into new dimensionless time series, with a mean of 1.0 that remains approximately statistically stationary through time. We used an option in the program that performs a second detrending with a stiff cubic spline (Cook and Peters 1981) to improve trend removal.

The program averages the transformed individual radii into a single time series, the standard chronology. One additional step in processing the chronology removes variance trend caused by reduction of sample size in the earliest part of the chronology (Shiyatov et al. 1990). Although the program generates several other types of chronologies, we used the standard chronologies in this research. Statistical properties of the 3 new baldcypress chronologies are shown in Table A2. The chronologies were further transformed by program PCREG (below) in the process of making reconstructions.

2. RECONSTRUCTIONS, THE "NESTING" CONCEPT AND CLIMATE RECONSTRUCTION PROGRAM PCREG

The climate division 5 reconstruction (Table A3), the only one not nested, uses 2 series of principal component factor scores that together incorporate 76.4% of the tree-ring variability in the 4 chronologies and account for 58% of the climate variance in calibration (Table A3a). The BSC and GPM Douglas-fir chronologies on the western edge of climate division 5 correlate better with June PDSI than the 2 baldcypress chronologies, GRP and KSS, on the eastern edge. KSS has the lowest correlation of the 4 chronologies. The superior climate sensitivity of the Douglas-fir chronologies is attributable in part to the more arid climate of their location in West Texas (Banner et al. 2010).

Except for division 5, the divisional reconstructions combine 2 different reconstructions, the first 1648–2008 that uses the Central Texas post oak chronology in combination with longer chronologies, but is limited to begin in 1648 by PCA (Tables A4, A6, A8). The second reconstructions for divisions 6, 7, and 8 only use long chronologies that span at least 1500–2008. The nonoverlapping portion of the longer reconstruction was appended to the shorter series after adjusting its mean and variance to match the shorter series in the overlap period. The reason this technique is preferred over averaging all the chronologies together into a single series or using multiple regression with the tree-ring chronologies, is that it permits the optimal use of all the available tree-ring data and the PCA methodology, which requires all the series input to be the same length. The reconstruction characteristics in Tables A4 through A10 demonstrate the utility of the nested reconstruction concept and chronology response to climate.

How well do the longer reconstructions match the short reconstructions in the 1648–2008 overlap period? The 1500–2008 reconstruction's 1648–2008 overlap period is not used, except for this comparison. The 2 division 6 reconstructions correlate very well in the overlap period (N=361, r=0.954, P<0.0001), indicating that they share about 91% of the variance and that the composite post oak chronology makes only a small improvement in the shorter reconstruction. The agreement is evident when the 2 reconstructions are overlaid (Fig. A1). The division 7 reconstructions do not correlate nearly as well (N=361, r=0.679, P<0.0001), sharing only 46% of the variance 1648–2008 (Fig. A2). The post oak chronology apparently does make a substantial improvement in that case.

The real surprise is that the 2 division 8 reconstructions share 64% of their variance and agree well (Fig. A3), considering that the longer reconstruction R^2 was only 0.18.

The nested reconstructions of divisions 6, 7, and 8 show that the advantages of using the shorter Central Texas post oak chronology (CENOAK; Table A1) vary from division to division. In each case, however, the 1648–2008 PCA factor scores account for more climate variance in regression than the 1500–2008 factor scores that do not include CENOAK, and CENOAK is consistently better correlated with climate than the other chronologies (Tables A4 to A9). Based on climate variance accounted for in regression alone, the reconstructions of division 6 (Tables A4 and A5) are the best, closely followed by division 5 (Table A3), and division 7 (Tables A6 and A7).

The case of reconstructing PDSI in division 8 deserves special consideration. The 1648–2008 reconstruction only accounts for 41.6% of the climate variance in regression (Table A8a). Of the 4 chronologies used (GRP, KSS, SBP and CENOAK), CENOAK is best correlated ($r=0.67$, $P<0.001$) and SBP is next ($r=0.43$, $P<0.001$), but the GRP correlation is barely significant ($r=0.22$, $P=0.048$), and KSS is barely positively and not significantly correlated ($r=0.06$, $P=0.590$) (Table A8a). The 1500–2008 division 8 calibration is the poorest, with only 18% of climate variance calibrated (Table A9a). Nevertheless, the long reconstruction passes all validation tests (Table A9b), indicating that the calibration percentage may be misleading. A trial 1500–2008 reconstruction that included the Big Cypress baldcypress chronology from North Central Louisiana (Table A1) fared worse (not shown). One of the 3 living tree oak chronologies averaged into the central Texas composite oak chronology and one baldcypress chronology, SBP, are actually located in division 8 (Fig. 1; Table A1). The other 2 new baldcypress chronologies are relatively far away, which decreases their correlation with division 8 PDSI. This result also confirms the importance of having long, climate-sensitive chronologies available locally for the best local reconstructions.

Some further analysis also indicates that the division 8 1500–1647 reconstruction may be better than the R^2 statistic indicates. Comparison of the 2 division 8 nested reconstructions, 1648–2008 and 1500–2008 in the period of overlap, shows stronger correlation ($r=0.80$, $P<0.0001$, 64% of the variance shared) than one would expect, given the disparity in the 2 percentages calibrated, $R^2=0.42$ and $R^2=0.18$, respectively. For this reason, the 1500–1647 segment of the division 8 nested reconstruction may actually be quite accurate.

The residuals, differences between the observations and the regression line (i.e., the predicted observation), should be randomly distributed if the model is valid, and are forced to sum to 0.0 (Draper and Smith 1981). The Durbin-Watson statistic (Draper and Smith 1981) tests for the serially random distribution of differences between the regression predictions and the actual observations (residuals), and all the regression models pass this test (Tables A3-A9). Another way to evaluate the relationships between climate and tree growth and the amount of error that might be expected in estimates is by the variance accounted for in regression, the R^2 (Draper and Smith 1981). By this criterion, the 1648–2008 portions of the nested reconstructions ought to contain less error than the 1500–1647 parts and the divisions 5, 6, and 7 reconstructions must contain less error than the division 8 reconstruction, although we have seen that some aspects of the latter assumption are open to question.

Program PCREG

We created climate reconstructions with program PCREG (Cook et al. 1994, 1999; LDEO website 2011). PCREG is a complicated program that performs many operations to calibrate a reconstruction with linear regression and validate that reconstruction against independent climatic data not used in the calibration. The sequence of PCREG operations is as follows:

1. Reads in multiple tree-ring chronologies and the single climate series to be reconstructed.
2. Autoregressively models ("whitens"; Meko 1981; Box et al. 1994) both the tree-ring chronologies and the climate series to remove persistence. This makes linear regression more efficient because the observations in the series become independent of each other (Draper and Smith 1981).
3. Performs a principal components analysis (PCA) (Cooley and Lohnes 1971) on the whitened tree-ring chronologies to generate new variables (factor scores) that maximize the common variance in the tree-ring chronologies. The factor score series are orthogonal (uncorrelated), so use of more than one in multiple regression does not run the risk of multicollinearity (Draper and Smith 1981).
4. Calibrates the reconstruction model by regressing (Draper and Smith 1981) the PCA factor score(s) (independent variable(s)) derived from the whitened tree-ring chronologies against the whitened climate variable (dependent variable).
5. Multiplies the PCA factor score(s) by the regression coefficients from operation 4 above to derive an intermediate reconstruction.
6. Adds the climatic AR model (Box et al. 1994; Meko 1981) removed in operation 2 above to the intermediate reconstruction in order to generate the final "reddened" reconstruction.
7. Compares the standard deviations of the observed and reconstructed climate variable in their overlap period.

The program makes the reconstructed variance match the observed variance by subtracting the reconstruction mean from that series, then multiplying the resulting anomaly series by the ratio of the observed and reconstructed standard deviation, and finally, adding the mean of the observed data back into the reconstructed series.

8. Compares the reconstruction to independent observed data not used in the calibration to measure the validity of the paleoclimatic estimates (Snee 1977; Fritts 2001).

3.

Table A1. Chronologies available for reconstruction of South Central Texas climate. Species codes: QUST=post oak, PSME=Douglas-fir, TADI=baldcypress, PIPO= ponderosa pine, PIED=pinyon pine.

Site Name / State / Code	Species	No. Trees	Latitude	Longitude	Dates / Comments
**Central Texas Post Oak Chronology/TX/CENOAK	QUST	187	Approx. center 29°45'N	Approx. center 97°10'W	1648–1995/Composite of the 7 sites immediately following
*Yegua Creek/ TX/ YEG	QUST	37	30°19'N	96°38'W	1658–1995
*Lavaca River/ TX/ HAL	QUST	42	29°18'N	96°58'W	1668–1995
*Coleto Creek/ TX/ COL	QUST	34	28°46'N	96°43'W	1682–1995
*Gonzales County Pioneer Village/TX/GPV	QUST	28	29°30'N	97°27'W	1649–1995
*Eggleston House/TX/EGG	QUST	18	29°31'N	97°25'W	1669–1845
*McBryde Log House/ TX/ YOK	QUST	21	29°15'N	97°05'W	1668–1847
*West-Adkisson Cabin/ TX/ WAD	QUST	7	30°30'N	97°46'W	1648–1853
**Big Bend National Park/ TX/ BSC	PSME	54	29°15'N	103°18'W	1473–1992
**Guadalupe Peak National Park/ TX/ GPM	PSME	55	30°26'N	104°51'W	1362–2008
Big Cypress State Park/ LA/ BIG	TADI		32°15'N	92°58'W	997–1988
El Malpais National Monument/ NM/ MLC	PSME		34°58'N	108°06'W	-136–1992
Echo Amphitheater/ NM /171	PSME		36°21'N	106°31'W	1362–1989
Satan Pass/ NM	PSME		35°36'N	108°08'W	1312–1990
Fort Burgwin/ NM	PIPO		36°15'N	105°31'W	1482–1989
Elephant Rock/ NM/ ERE	PIPO		36°42'N	105°29'W	1391–1987
Agua Fria/ NM/ AFN	PIED		34°14'N	108°37'W	1403–1987
Ft. Wingate/ NM/ 283	PIED		35°26'	108°32'W	1478–1972
Turkey Springs/ NM/ 273	PIED		35°24'	108°31'W	1411–1972

* Part of the composite Central Texas post oak chronology used in reconstructions

** Used in reconstructions

4.

Table A2a. Characteristics of chronologies collected in South Central Texas used in reconstructions. All are baldcypress (*Taxodium distichum*).

Site Name / Code	Lat. / Long.	Elev. (m)	No. Radii	No.Trees	Dates	County	Site Type
Guadalupe R St Pk/GRP	29˚52’N/ 98˚30’W	300	37	13	1486–2009	Kendall	Hill country, riverine
Krause Springs/KSS	30˚29’N/ 98˚09’W	230	55	28	1423–2009	Burnet	Hill country, stream
San Bernard R Pk/SBP	29˚26’N/ 96˚01’W	27	27	13	1447–2009	Ft. Bend, Wharton	Coastal plain, riverine

Table A2a. (Contd.)

Site Code	Annual Precip.	Substrate	Hydrology	Additional information
GRP	29-33” (74-84cm)	Limestone	River bank	Some human impact
KSS	29-33” (74-84cm)	Limestone	Mixed: stream bank, valley slopes	Very large human impact
SBP	49-53” (124-135cm)	Alluvium	River bank	Minimal human impact

Table A2b. Chronology statistics.

Site name / Code	Mean Sens.[a]	Std. Dev.	Serial[b] Corr.	AR Model	Division June PDSI Correlation / Probability (1931–2008)			
					5	6	7	8
Guadalupe R. State Park/GRP	0.275	0.291	0.398	2	0.22/ <0.05	0.65/ <0.001	0.32/ <0.01	0.25/ <0.03
Krause Springs/KSS	0.225	0.243	0.422	3	0.06/ =0.14	0.29/ <0.01	0.19/ <0.09	0.02/ =0.88
San Bernard R. Pk/SBP	0.418	0.409	0.235	3	0.18/ =0.12	0.51/ <0.001	0.53/ <0.001	0.45/ <0.001

Table A2c. Common period statistics.

Site name / Code	Common Period	Signal / Noise	Pearson[c] Corr.	Mean[a] Sens.	Std. Dev.	Serial[c] Corr.
Guadalupe R. State Park/GRP	1890–2008	6.692	0.255	0.388	0.461	0.392
Krause Springs/KSS	1905–2008	10.947	0.225	0.388	0.497	0.467
San Bernard R. Bates Allen Park/SBP	1905–2008	10.418	0.451	0.522	0.529	0.297

[a] Mean sensitivity: “… the average relative difference from one ring width to the next, calculated by dividing the absolute value of the differences between each pair of measurements by the average of the paired measurements, then averaging the quotients for all pairs in the tree ring series …” (Kaennel and Schweingruber 1995) (Fritts 2001).

[b] The Pearson product moment correlation coefficient (Steel and Torrie 1980) between $Year_t$ and $Year_{t-1}$, a measure of persistence in the time series. The relatively high persistence at the KSS site may indicate a lesser sensitivity to climate in that chronology relative to the others.

[c] Pearson product moment correlation coefficient between radii (Steel and Torrie 1980). The low KSS correlation may indicate a lesser sensitivity to climate in that chronology relative to the others.

5. **Table A3a.** Texas climate division 5 (Trans Pecos) reconstruction 1500–2008 of June PDSI, calibration 1931–2008.

	PCA % Variance		Regression		Serial Corr. Residuals	Durbin-Watson Statistic[b]
Chronologies Used	**1st PC**	**2nd PC**	**#PCs Used**	**R^2 adj.[a]**		
GRP,KSS,BSC,GPM	50.2	26.2	2	0.580	-0.135	2.24NS

NS Not significant, i.e., there is greater than a 5% probability that the result occurred by chance.

[a] R^2 adjusted downward for loss of degrees of freedom (Draper and Smith 1981).

[b] Autocorrelation of the residuals from regression, tested with the Durbin-Watson statistic (Draper and Smith 1981). Failure to reject the null hypothesis indicates that the residuals occur randomly, an indication that the regression model is valid.

Table A3a. (Cont'd)

Chronology	Beta[#]	Std. Error	Corr.	Prob.
GRP: Guadalupe R.	0.0990	0.0260	0.29	0.010
KSS: Krause Springs	-0.0134	0.0402	0.20	0.072
BSC: Big Bend NP	0.4145	0.0309	0.69	0.001
GPM: Guadalupe Peak NP	0.3966	0.0272	0.70	0.001

[#] Regression coefficient in terms of original variable.

Table A3b. Validation 1895–1930 for reconstruction 1500–2008 of Texas climate division 5 (Trans Pecos) June PDSI.

Test	Statistic	Difference	t-stat. or z-score	Prob.	Remark
Equality of means[a]	-------	-0.38	-0.734	0.530	No sig. dif. is desired result
Cross-product means[b]	-------	3.81	3.390	<0.001	
Sign test (+/-)[c]	21/15	--------	0.833	0.202	Only validation failure
Correlation Coefficient[d]	0.53	--------	3.620	<0.0000	
Reduction of Error[e]	0.28	--------	No formal test of significance		
Coefficient of Efficiency[e]	0.27	--------	No formal test of significance		

[a] Paired comparison of observed and reconstructed data means (Steel and Torrie 1980). Note that no difference is the desired result.

[b] Tests the relative magnitude of departures from the mean in the same or opposite directions when reconstruction and observed are compared for each year. Means are subtracted from each series and the residuals are multiplied. A positive product is a "hit." If either observed or reconstructed data lie very near the mean, the year is omitted from the test.

[c] Nonparametric test of the ratio of the number of "hits" to "misses" in the cross-product means test above (Conover 1980).

[d] Pearson product moment correlation coefficient (Steel and Torrie 1980).

[e] Varies from 1.0 to negative infinity. Any positive result is considered evidence of useful information in the paleoclimatic reconstruction (Fritts 2001). The coefficient of efficiency is the more stringent test.

6. **Table A4a.** Texas climate division 6 (Edwards Plateau) reconstruction 1648–2008 of June PDSI, calibration 1931–2008.

Chronologies Used	PCA % Variance		Regression		Serial Corr.[b] of Residuals	Durbin-Watson Statistic[b]
	1st PC	2nd PC	#PCs Used	R^2 adj.[a]		
GRP,KSS,SBP,CENOAK,BSC,GPM	67.0	------	1	0.674	-0.075	2.12NS

NS Not significant, i.e., there is greater than a 5% probability that the result occurred by chance.

[a] R^2 adjusted downward for loss of degrees of freedom (Draper and Smith 1981).

[b] Autocorrelation of the residuals from regression, tested with the Durbin-Watson statistic (Draper and Smith 1981). Failure to reject the null hypothesis indicates that the residuals occur randomly, an indication that the regression model is valid.

Table A4a. (Cont'd)

Chronology	Beta[#]	Std. Error	Corr.	Prob.
GRP: Guadalupe R.	0.2118	0.0071	0.53	<0.000
KSS: Krause Springs	0.1561	0.0039	0.37	<0.001
SBP: San Bernard R.	0.1793	0.0051	0.51	<0.000
CENOAK: Central TX postoak	0.2411	0.0092	0.67	<0.000
BSC: Big Bend NP	0.2345	0.0087	0.66	<0.000
GPM: Guadalupe Peak NP	0.1984	0.0062	0.49	<0.000

[#] Regression coefficient in terms of original variable.

Table A4b. Validation 1895–1930 for reconstruction 1648–2008 of Texas climate division 6 (Edwards Plateau) June PDSI.

Test	Statistic	Difference	t-stat. or z-score	Prob.	Remark
Equality of means[a]	-------	-0.12	-0.020	0.982	No sig. dif. is desired result
Cross-product means[b]	-------	5.68	3.183	<0.002	
Sign test (+/-)[c]	27/9	--------	2.833	0.002	
Correlation Coefficient[d]	0.73	--------	6.159	<0.0000	
Reduction of Error[e]	0.50	--------	No formal test of significance		
Coefficient of Efficiency[e]	0.50	--------	No formal test of significance		

[a] Paired comparison of observed and reconstructed data means (Steel and Torrie 1980). Note that no difference is the desired result.

[b] Tests the relative magnitude of departures from the mean in the same or opposite directions when reconstruction and observed are compared for each year. Means are subtracted from each series and the residuals are multiplied. A positive product is a "hit." If either observed or reconstructed data lie very near the mean, the year is omitted from the test.

[c] Nonparametric test of the ratio of the number of "hits" to "misses" in the cross-product means test above (Conover 1980).

[d] Pearson product moment correlation coefficient (Steel and Torrie 1980).

[e] Varies from 1.0 to negative infinity. Any positive result is considered evidence of useful information in the paleoclimatic reconstruction (Fritts 2001). The coefficient of efficiency is the more stringent test.

7. **Table A5a.** Texas climate division 6 (Edwards Plateau) reconstruction 1500–2008 of June PDSI, calibration 1931–2008. Used 1500–1647 in combination with 1648-2008 reconstruction (Table A4).

Chronologies Used	PCA % Variance		Regression		Serial Corr.[b] of Residuals	Durbin-Watson Statistic[b]
	1st PC	2nd PC	#PCs Used	R^2 adj.[a]		
GRP,KSS,SBP,BSC,GPM	43.6	23.1	1	0.599	-0.031	2.04NS

NS Not significant, i.e., there is greater than a 5% probability that the result occurred by chance.

[a] R^2 adjusted downward for loss of degrees of freedom (Draper and Smith 1981).

[b] Autocorrelation of the residuals from regression, tested with the Durbin-Watson statistic (Draper and Smith 1981). Failure to reject the null hypothesis indicates that the residuals occur randomly, an indication that the regression model is valid.

Table A5a. (Cont'd)

Chronology	Beta[#]	Std. Error	Corr.	Prob.
GRP: Guadalupe R. SP	0.2512	0.0111	0.53	<0.000
KSS: Krause Springs	0.2068	0.0075	0.37	<0.001
SBP: San Bernard R.	0.1916	0.0065	0.51	<0.000
BSC: Big Bend NP	0.2519	0.0112	0.49	<0.000
GPM: Guadalupe Peak NP	0.2668	0.0125	0.66	<0.000

[#] Regression coefficient in terms of original variable.

Table A5b. Validation 1895–1930 for reconstruction 1500–2008 of Texas climate division 6 (Edwards Plateau) June PDSI.

Test	Statistic	Difference	t-stat. or z-score	Prob.	Remark
Equality of means[a]	-------	0.194	0.327	0.742	No sig. dif. is desired result
Cross-product means[b]	-------	5.25	3.648	<0.0005	
Sign test (+/-)[c]	25/11	--------	2.167	0.015	
Correlation Coefficient[d]	0.73	--------	6.159	<0.0000	
Reduction of Error[e]	0.50	--------	No formal test of significance		
Coefficient of Efficiency[e]	0.50	--------	No formal test of significance		

[a] Paired comparison of observed and reconstructed data means (Steel and Torrie 1980). Note that no difference is the desired result.

[b] Tests the relative magnitude of departures from the mean in the same or opposite directions when reconstruction and observed are compared for each year. Means are subtracted from each series and the residuals are multiplied. A positive product is a "hit." If either observed or reconstructed data lie very near the mean, the year is omitted from the test.

[c] Nonparametric test of the ratio of the number of "hits" to "misses" in the cross-product means test above (Conover 1980).

[d] Pearson product moment correlation coefficient (Steel and Torrie 1980).

[e] Varies from 1.0 to negative infinity. Any positive result is considered evidence of useful information in the paleoclimatic reconstruction (Fritts 2001). The coefficient of efficiency is the more stringent test.

8. **Table A6a.** Texas climate division 7 (South Central) reconstruction 1648–2008 of June PDSI, calibration 1931–2008.

Chronologies Used	PCA % Variance		Regression		Serial Corr.[b] of Residuals	Durbin-Watson Statistic[b]
	1st PC	2nd PC	#PCs Used	R^2 adj.[a]		
GRP,KSS,SBP,CENOAK	51.7	20.8	2	0.595	0.084	1.83NS

NS Not significant, i.e., there is greater than a 5% probability that the result occurred by chance.

[a] R^2 adjusted downward for loss of degrees of freedom (Draper and Smith 1981).

[b] Autocorrelation of the residuals from regression, tested with the Durbin-Watson statistic (Draper and Smith 1981). Failure to reject the null hypothesis indicates that the residuals occur randomly, an indication that the regression model is valid.

Table 6a. (Cont'd)

Chronology	Beta[#]	Std. Error	Corr.	Prob.
GRP: Guadalupe R.	0.2013	0.0178	0.45	<0.000
KSS: Krause Springs	0.0116	0.0557	0.30	<0.008
SBP: San Bernard R.	0.3746	0.0251	0.52	<0.000
CENOAK: Central TX postoak	0.4077	0.0314	0.79	<0.000

[#] Regression coefficient in terms of original variable.

Table 6b. Validation 1895–1930 for reconstruction 1648–2008 of Texas climate division 7 (South Central) June PDSI.

Test	Statistic	Difference	t-stat. or z-score	Prob.	Remark
Equality of means[a]	-------	-0.43	-0.678	0.505	No sig. dif. is desired result
Cross-product means[b]	-------	4.24	2.149	0.0184	
Sign test (+/-)[c]	32/4	--------	4.500	0.000	
Correlation Coefficient[d]	0.76	--------	6.797	<0.0000	
Reduction of Error[e]	0.52	--------	No formal test of significance		
Coefficient of Efficiency[e]	0.52	--------	No formal test of significance		

[a] Paired comparison of observed and reconstructed data means (Steel and Torrie 1980). Note that no difference is the desired result.

[b] Tests the relative magnitude of departures from the mean in the same or opposite directions when reconstruction and observed are compared for each year. Means are subtracted from each series and the residuals are multiplied. A positive product is a "hit." If either observed or reconstructed data lie very near the mean, the year is omitted from the test.

[c] Nonparametric test of the ratio of the number of "hits" to "misses" in the cross-product means test above (Conover 1980).

[d] Pearson product moment correlation coefficient (Steel and Torrie 1980).

[e] Varies from 1.0 to negative infinity. Any positive result is considered evidence of useful information in the paleoclimatic reconstruction (Fritts 2001). The coefficient of efficiency is the more stringent test.

9. **Table A7a.** Texas climate division 7 (South Central) reconstruction 1500–2008 of June PDSI, calibration 1931–2008. Used 1500–1647 in combination with 1648–2008 reconstruction (Table A6).

Chronologies Used	PCA % Variance		Regression		Serial Corr.[b] of Residuals	Durbin-Watson Statistic[b]
	1st PC	2nd PC	#PCs Used	R^2 adj.[a]		
GRP,KSS,SBP,BSC,GPM	43.6	23.1	1	0.433	0.086	1.81NS

NS Not significant, i.e., there is greater than a 5% probability that the result occurred by chance.

[a] R^2 adjusted downward for loss of degrees of freedom (Draper and Smith 1981).

[b] Autocorrelation of the residuals from regression, tested with the Durbin-Watson statistic (Draper and Smith 1981). Failure to reject the null hypothesis indicates that the residuals occur randomly, an indication that the regression model is valid.

Table A7a. (Cont'd)

Chronology	Beta[#]	Std. Error	Corr.	Prob.
GRP: Guadalupe R. SP	0.2143	0.0132	0.45	<0.000
KSS: Krause Springs	0.1764	0.0090	0.30	<0.008
SBP: San Bernard R.	0.1634	0.0077	0.52	<0.000
BSC: Big Bend NP	0.2149	0.0133	0.40	<0.000
GPM: Guadalupe Peak NP	0.2726	0.0149	0.52	<0.000

[#] Regression coefficient in terms of original variable.

Table A7b. Validation 1895–1930 for reconstruction 1500–2008 of Texas climate division 7 (South Central) June PDSI.

Test	Statistic	Difference	t-stat. or z-score	Prob.	Remark
Equality of means[a]	-------	-0.189	-0.345	0.730	No sig. dif. is desired result
Cross-product means[b]	-------	4.32	3.474	<0.0008	
Sign test (+/-)[c]	24/12	--------	1.833	0.0334	
Correlation Coefficient[d]	0.65	--------	4.986	<0.0000	
Reduction of Error[e]	0.42	--------	No formal test of significance		
Coefficient of Efficiency[e]	0.42	--------	No formal test of significance		

[a] Paired comparison of observed and reconstructed data means (Steel and Torrie 1980). Note that no difference is the desired result.

[b] Tests the relative magnitude of departures from the mean in the same or opposite directions when reconstruction and observed are compared for each year. Means are subtracted from each series and the residuals are multiplied. A positive product is a "hit." If either observed or reconstructed data lie very near the mean, the year is omitted from the test.

[c] Nonparametric test of the ratio of the number of "hits" to "misses" in the cross-product means test above (Conover 1980).

[d] Pearson product moment correlation coefficient (Steel and Torrie 1980).

[e] Varies from 1.0 to negative infinity. Any positive result is considered evidence of useful information in the paleoclimatic reconstruction (Fritts 2001). The coefficient of efficiency is the more stringent test.

10. **Table A8a.** Texas climate division 8 (Upper Coast) reconstruction 1648–2008 of June PDSI, calibration 1931–2008.

Chronologies Used	PCA % Variance		Regression		Serial Corr.[b] of Residuals	Durbin-Watson Statistic[b]
	1st PC	2nd PC	#PCs Used	R^2 adj.[a]		
GRP,KSS,SBP,CENOAK	51.7	20.8	2	0.416	0.093	1.81NS

NS Not significant, i.e., there is greater than a 5% probability that the result occurred by chance.

[a] R^2 adjusted downward for loss of degrees of freedom (Draper and Smith 1981).

[b] Autocorrelation of the residuals from regression, tested with the Durbin-Watson statistic (Draper and Smith 1981). Failure to reject the null hypothesis indicates that the residuals occur randomly, an indication that the regression model is valid.

Table A8a. (Cont'd)

Chronology	Beta[#]	Std. Error	Corr.	Prob.
GRP: Guadalupe R.	0.0830	0.0214	0.22	<0.048
KSS: Krause Springs	-0.2072	0.0668	0.06	<0.590
SBP: San Bernard R.	0.3590	0.0302	0.43	<0.000
CENOAK: Central TX postoak	0.4021	0.0377	0.67	<0.000

[#] Regression coefficient in terms of original variable.

Table A8b. Validation 1895–1930 for reconstruction 1648–2008 of Texas climate division 8 (Upper Coast) June PDSI.

Test	Statistic	Difference	t-stat. or z-score	Prob.	Remark
Equality of means[a]	-------	-0.43	-0.904	0.630	No sig. dif. is desired result
Cross-product means[b]	-------	3.25	3.952	<0.0003	
Sign test (+/-)[c]	30/6	--------	3.833	<0.0001	
Correlation Coefficient[d]	0.78	--------	7.285	<0.0000	
Reduction of Error[e]	0.57	--------	No formal test of significance		
Coefficient of Efficiency[e]	0.57	--------	No formal test of significance		

[a] Paired comparison of observed and reconstructed data means (Steel and Torrie 1980). Note that no difference is the desired result.

[b] Tests the relative magnitude of departures from the mean in the same or opposite directions when reconstruction and observed are compared for each year. Means are subtracted from each series and the residuals are multiplied. A positive product is a "hit." If either observed or reconstructed data lie very near the mean, the year is omitted from the test.

[c] Nonparametric test of the ratio of the number of "hits" to "misses" in the cross-product means test above (Conover 1980).

[d] Pearson product moment correlation coefficient (Steel and Torrie 1980).

[e] Varies from 1.0 to negative infinity. Any positive result is considered evidence of useful information in the paleoclimatic reconstruction (Fritts 2001). The coefficient of efficiency is the more stringent test.

11. **Table A9a.** Texas climate division 8 (Upper Coast) reconstruction 1500–2008 of June PDSI, calibration 1931–2008. Used 1500–1647 in combination with 1648–2008 reconstruction (Table A8).

Chronologies Used	PCA % Variance		Regression		Serial Corr.[b] of Residuals	Durbin-Watson Statistic[b]
	1st PC	2nd PC	#PCs Used	R^2 adj.[a]		
GRP,KSS,SBP	55.9	24.3	2	0.180	0.090	1.82NS

NS Not significant, i.e., there is greater than a 5% probability that the result occurred by chance.

[a] R^2 adjusted downward for loss of degrees of freedom (Draper and Smith 1981).

[b] Autocorrelation of the residuals from regression, tested with the Durbin-Watson statistic (Draper and Smith 1981). Failure to reject the null hypothesis indicates that the residuals occur randomly, an indication that the regression model is valid.

Table A9a. (Cont'd)

Chronology	Beta[#]	Std. Error	Corr.	Prob.
GRP: Guadalupe R. SP	0.0786	0.0338	0.22	<0.046
KSS: Krause Springs	-0.0674	0.0645	0.06	<0.583
SBP: San Bernard R.	0.4338	0.1023	0.43	<0.000

[#] Regression coefficient in terms of original variable.

Table A9b. Validation 1895–1930 for reconstruction 1500–2008 of Texas climate division 8 (Upper Coast) June PDSI.

Test	Statistic	Difference	t-stat. or z-score	Prob.	Remark
Equality of means[a]	-------	-0.075	-0.185	0.848	No sig. dif. is desired result
Cross-product means[b]	-------	1.36	2.841	<0.0037	
Sign test (+/-)[c]	27/9	--------	2.833	0.0023	
Correlation Coefficient[d]	0.60	--------	4.425	<0.0001	
Reduction of Error[e]	0.34	--------	No formal test of significance		
Coefficient of Efficiency[e]	0.34	--------	No formal test of significance		

[a] Paired comparison of observed and reconstructed data means (Steel and Torrie 1980). Note that no difference is the desired result.

[b] Tests the relative magnitude of departures from the mean in the same or opposite directions when reconstruction and observed are compared for each year. Means are subtracted from each series and the residuals are multiplied. A positive product is a "hit." If either observed or reconstructed data lie very near the mean, the year is omitted from the test.

[c] Nonparametric test of the ratio of the number of "hits" to "misses" in the cross-product means test above (Conover 1980).

[d] Pearson product moment correlation coefficient (Steel and Torrie 1980).

[e] Varies from 1.0 to negative infinity. Any positive result is considered evidence of useful information in the paleoclimatic reconstruction (Fritts 2001). The coefficient of efficiency is the more stringent test.

12. **Table A10.** Statistics of the Trans Pecos (division 5) June PDSI reconstruction 1500–2008 and nested June PDSI reconstructions of Edwards Plateau (division 6), South Central (division 7), and Upper Coast (division 8) 1500–2008.

Statistic	Reconstructed Data (Divisions)				Observed Data (Divisions)1895–2008			
	5	6	7	8	5	6	7	8
N	509	509	509	509	114	114	114	114
Mean	-0.11	0.02	0.07	0.24	-0.22	-0.00	-0.11	0.04
Median	-0.07	0.06	-0.01	-0.06	-0.76	-0.23	-0.34	-0.21
Std.Dev.	2.98	2.82	2.94	2.30	2.71	2.78	2.74	2.21
Variance	8.90	7.96	8.62	5.29	7.33	7.72	7.52	4.87
Range	16.18	16.15	17.54	13.62	13.61	10.91	12.28	10.06
Maximum	8.66	8.44	10.87	8.81	9.44	5.33	6.39	5.31
Minimum	-7.52	-7.71	-6.67	-4.81	-4.17	-5.58	-5.89	-4.75
Serial[a] Corr.	0.34	0.20	0.32	0.12	0.14	-0.01	0.16	0.08
Normal[b] Distrib.?	P>0.15 Yes	P>0.15 Yes	P>0.15 Yes	P<0.01 No	P<0.01 No	P=0.11 Yes	P=0.04 No	P=0.12 Yes
Skewness	0.11	0.05	0.26	0.47	1.13	0.23	0.07	0.11
Kurtosis	-0.23	-0.14	0.16	0.22	1.52	-0.94	-0.70	-0.65

[a] The Pearson product moment correlation coefficient (Steel and Torrie 1980) between Year_t and Year_{t-1}.

[b] Kolmogorov-Smirnov nonparametric test of distribution normality (Conover 1980; Steel and Torrie 1980).

13. **Table A11.** Reconstructed, observed June PDSI data for TX divs 5,6,7,8(Trans Pecos, Edwards Plateau, S. Central, Upper Coast, respectively); The observed data 1895–2009 was downloaded from the NOAA National Climatic Data Center website: http://www1.ncdc.noaa.gov/pub/data/cirs.

Chronologies used (#s 1-3 baldcypress [*Taxodium distichum*], #4 post oak [*Quercus stellata*] an average of 3 living tree and 4 historic timber chronologies, #s 5-6 Douglas-fir [*Pseudotsuga menziesii*]):

1. Guadalupe R. St. Park (GRP) 1486–2009, 29°52.294’N, 98°29.958’W; 37 radii
2. Krause Springs Park (KSS) 1423–2009, 30°28.789’N, 98°08.69’W; 55 radii
3. San Bernard R., Bates-Allen Park (SBP)1447–2009, 29°25.901’N, 96°00.552’W; 27 radii
4. Central TX post oak chronology (CENOAK) 1648–1995,composed of 3 live tree and 4 historical chronologies; extended to 2008 by regression with the average of climate divisions 6,7 and 8; Constituent chronologies: YEG (Yegua Ck 30.317°N 96.633°W, 1658–995); HAL (Lavaca R [or Hallettsville] 29.308°N 96.967°W, 1668–1995); COL (Coleto Ck 28.767°N 97.183°W, 1682–1995); GPV (Gonzales Pioneer Village 29.500°N 97.450°W, 649–1995); EGG (Eggleston House 29.517°N 97.417°W, 1669–1845); YOK (McBryde [or Yoakum] Log House 29.250°N 97.083°W, 1668–1847); WAD (West-Adkisson House 30.50°N 97.767°W, 1648–1853)
5. Big Bend Nat. Park (BSC) 1473–1992, 29.245°N 103.294°W; 95 radii; extended to 2008 by regression with climate division 5
6. Guadalupe Peak Nat. Park (GPM) 1362–2008, 31.892°N, 104.851°W; 105 radii

Reconstructions:

RTX5: from GRP,KSS,BSC,GPM
RTX6: 1648–2008 from GRP, KSS, SBP, CENOAK, BSC, GPM
1500–1647 from GRP, KSS, SBP, BSC, GPM
RTX7: 1648–2008 from GRP, KSS, SBP, CENOAK
1500–1647 from GRP, KSS, SBP, BSC, GPM (better than reconstruction from GRP,KSS,SBP only)
RTX8: 1648–2008 from GRP, KSS, SBP, CENOAK
1500–1647 from GRP, KSS, SBP (adding BIG, a long LA baldcypress chronology, did not help)

YEAR	RTX5	RTX6	RTX7	RTX8	OTX5	OTX6	OTX7	OTX8
1500	1.07	-0.05	0.01	-2.25	.	.	.	.
1501	-2.40	-0.81	-0.76	0.22	.	.	.	.
1502	-1.69	-1.77	-1.84	0.77	.	.	.	.
1503	-1.99	-0.71	-0.95	1.07	.	.	.	.
1504	-1.15	-2.44	-2.53	1.72	.	.	.	.
1505	0.36	-0.19	-0.54	1.98	.	.	.	.
1506	1.13	2.19	2.15	4.96	.	.	.	.
1507	2.90	3.19	3.57	1.95	.	.	.	.
1508	3.02	1.53	2.14	0.56	.	.	.	.
1509	4.07	4.51	4.88	1.40	.	.	.	.
1510	2.19	2.68	3.49	0.41	.	.	.	.
1511	6.09	7.29	7.87	1.29	.	.	.	.
1512	0.74	0.64	1.93	0.52	.	.	.	.
1513	4.10	4.48	4.82	3.01	.	.	.	.
1514	-0.27	-1.58	-0.77	-3.13	.	.	.	.
1515	-1.92	-2.24	-2.31	0.12	.	.	.	.
1516	-3.36	-2.13	-2.44	-0.67	.	.	.	.
1517	-4.80	-0.86	-1.19	4.59	.	.	.	.
1518	0.04	1.17	1.02	-1.48	.	.	.	.
1519	3.23	1.31	1.51	-1.57	.	.	.	.
1520	2.15	0.44	0.73	-1.47	.	.	.	.
1521	0.55	-0.00	0.16	-4.76	.	.	.	.
1522	-0.78	-0.91	-0.83	-1.05	.	.	.	.
1523	-1.37	-2.42	-2.49	-0.65	.	.	.	.
1524	-5.82	-4.38	-4.71	-2.30	.	.	.	.
1525	-4.11	-3.53	-4.22	-2.41	.	.	.	.
1526	3.81	3.93	3.29	-1.70	.	.	.	.
1527	-0.83	1.11	1.68	5.31	.	.	.	.
1528	-7.08	-6.84	-6.50	-1.10	.	.	.	.
1529	-2.15	-1.06	-2.03	-0.50	.	.	.	.
1530	1.61	3.88	3.59	5.30	.	.	.	.
1531	-1.55	-1.52	-0.90	-1.50	.	.	.	.
1532	-4.24	-3.79	-3.87	1.74	.	.	.	.
1533	-1.41	0.59	0.02	2.39	.	.	.	.
1534	-0.08	2.99	3.03	2.95	.	.	.	.
1535	-0.65	0.23	0.76	-0.12	.	.	.	.
1536	5.54	3.81	3.96	1.67	.	.	.	.
1537	3.60	2.57	3.24	-0.35	.	.	.	.
1538	-6.54	-6.40	-5.82	2.05	.	.	.	.
1539	-0.27	-1.04	-1.92	-2.50	.	.	.	.
1540	4.31	4.72	4.45	1.55	.	.	.	.
1541	1.28	2.07	2.81	-0.10	.	.	.	.
1542	-6.50	-6.24	-5.73	2.62	.	.	.	.
1543	2.07	4.87	3.99	2.31	.	.	.	.
1544	-0.69	-1.08	-0.40	-2.53	.	.	.	.
1545	-1.04	-0.03	-0.04	2.43	.	.	.	.
1546	-0.16	2.50	2.53	2.52	.	.	.	.
1547	-4.16	-0.38	0.07	-0.39	.	.	.	.
1548	-0.71	0.87	0.93	1.04	.	.	.	.
1549	0.56	0.30	0.49	-1.72	.	.	.	.
1550	2.34	0.49	0.61	2.89	.	.	.	.
1551	-1.10	-4.14	-3.98	-0.82	.	.	.	.
1552	-1.14	-2.96	-3.54	-0.51	.	.	.	.
1553	2.49	1.90	1.38	-2.09	.	.	.	.
1554	6.11	3.77	4.02	0.04	.	.	.	.
1555	6.65	4.93	5.59	1.88	.	.	.	.
1556	7.35	5.34	6.25	-1.19	.	.	.	.
1557	2.66	1.28	2.31	2.30	.	.	.	.
1558	-0.69	1.84	2.24	2.57	.	.	.	.
1559	-2.82	-3.25	-2.84	-0.84	.	.	.	.
1560	-0.58	-1.80	-2.20	-1.64	.	.	.	.
1561	-1.72	-3.34	-3.63	-3.95	.	.	.	.
1562	-3.17	-4.52	-5.03	-2.78	.	.	.	.
1563	1.03	0.45	-0.30	0.64	.	.	.	.
1564	1.72	0.31	0.30	0.04	.	.	.	.
1565	3.96	1.70	1.79	1.38	.	.	.	.
1566	2.44	-0.25	0.08	0.34	.	.	.	.
1567	-2.95	-2.91	-2.84	-2.16	.	.	.	.
1568	-1.04	0.95	0.55	1.77	.	.	.	.
1569	-0.94	3.89	4.01	6.80	.	.	.	.
1570	0.31	6.04	6.70	3.30	.	.	.	.
1571	-1.77	-1.79	-0.68	0.08	.	.	.	.
1572	-1.46	-4.28	-4.33	-2.41	.	.	.	.
1573	-4.58	-2.19	-2.82	0.92	.	.	.	.

Table A11 (Cont'd)

YEAR	RTX5	RTX6	RTX7	RTX8	OTX5	OTX6	OTX7	OTX8
1574	-3.91	-4.05	-4.44	-2.03	.	.	.	.
1575	-2.34	-1.35	-2.00	3.28	.	.	.	.
1576	-1.62	0.06	-0.21	2.22	.	.	.	.
1577	-2.71	-2.18	-2.16	-1.11	.	.	.	.
1578	0.91	2.84	2.54	5.28	.	.	.	.
1579	-3.16	-3.70	-3.24	-2.92	.	.	.	.
1580	-0.77	-0.87	-1.33	-0.75	.	.	.	.
1581	0.93	0.65	0.48	-1.15	.	.	.	.
1582	-0.44	-0.63	-0.51	-1.05	.	.	.	.
1583	-2.34	-0.80	-0.83	0.07	.	.	.	.
1584	-2.75	1.07	0.98	3.64	.	.	.	.
1585	-6.36	-0.80	-0.60	-1.86	.	.	.	.
1586	1.59	2.50	2.44	2.07	.	.	.	.
1587	1.22	-2.00	-1.56	-3.86	.	.	.	.
1588	1.73	2.01	1.80	1.73	.	.	.	.
1589	-2.64	-2.87	-2.53	-0.81	.	.	.	.
1590	-0.34	-0.39	-0.74	-3.79	.	.	.	.
1591	-2.56	-2.11	-2.18	-1.15	.	.	.	.
1592	-1.47	1.35	1.05	4.14	.	.	.	.
1593	-1.09	2.39	2.59	6.13	.	.	.	.
1594	2.63	2.49	2.94	-0.89	.	.	.	.
1595	0.74	-2.15	-1.63	-0.39	.	.	.	.
1596	0.12	-1.47	-1.68	2.45	.	.	.	.
1597	-0.40	-2.52	-2.74	-2.36	.	.	.	.
1598	0.13	-0.03	-0.41	-0.40	.	.	.	.
1599	-1.22	0.89	0.87	0.46	.	.	.	.
1600	-1.14	-0.50	-0.32	-0.58	.	.	.	.
1601	-4.90	-5.48	-5.46	-1.44	.	.	.	.
1602	-0.05	1.11	0.29	1.17	.	.	.	.
1603	1.96	0.91	1.00	-0.97	.	.	.	.
1604	-0.43	-1.91	-1.70	-1.54	.	.	.	.
1605	-2.90	-2.35	-2.57	-0.68	.	.	.	.
1606	-2.00	-3.37	-3.71	-2.97	.	.	.	.
1607	0.13	2.49	1.94	2.19	.	.	.	.
1608	0.28	-0.64	-0.28	-3.69	.	.	.	.
1609	2.43	1.84	1.84	2.02	.	.	.	.
1610	3.81	1.71	2.04	-0.63	.	.	.	.
1611	2.89	2.98	3.34	-1.20	.	.	.	.
1612	3.99	-0.02	0.55	-1.32	.	.	.	.
1613	1.17	-0.85	-0.71	-2.00	.	.	.	.
1614	-3.58	-3.57	-3.63	-0.10	.	.	.	.
1615	-3.13	-1.15	-1.67	-0.37	.	.	.	.
1616	1.49	0.39	0.17	-0.62	.	.	.	.
1617	0.21	1.64	1.71	2.24	.	.	.	.
1618	0.53	0.17	0.48	1.68	.	.	.	.
1619	0.91	-2.16	-2.03	-1.63	.	.	.	.
1620	2.84	3.47	3.18	6.96	.	.	.	.
1621	2.60	0.38	0.93	-0.99	.	.	.	.
1622	1.63	0.43	0.63	-1.33	.	.	.	.
1623	-1.39	-3.11	-2.95	-1.40	.	.	.	.
1624	-3.46	-2.48	-2.90	0.01	.	.	.	.
1625	-0.33	0.90	0.49	0.60	.	.	.	.
1626	-2.40	-2.78	-2.65	-2.35	.	.	.	.
1627	2.81	2.62	2.24	-0.56	.	.	.	.
1628	0.44	-0.01	0.39	-0.40	.	.	.	.
1629	5.27	4.05	4.14	3.33	.	.	.	.
1630	2.84	0.93	1.63	3.47	.	.	.	.
1631	-0.65	0.19	0.50	2.84	.	.	.	.
1632	-5.51	-5.18	-5.04	-2.15	.	.	.	.
1633	-5.49	-4.12	-4.85	-0.37	.	.	.	.
1634	1.28	1.06	0.34	3.40	.	.	.	.
1635	2.20	2.47	2.56	0.71	.	.	.	.
1636	0.03	1.78	2.23	1.79	.	.	.	.
1637	2.00	4.81	5.20	2.38	.	.	.	.
1638	0.84	0.80	1.67	-1.32	.	.	.	.
1639	4.18	6.20	6.49	3.76	.	.	.	.
1640	4.23	3.61	4.67	-1.64	.	.	.	.
1641	2.91	-0.81	-0.02	-0.93	.	.	.	.
1642	0.99	-1.25	-1.20	-2.17	.	.	.	.
1643	2.00	-0.98	-1.12	-1.94	.	.	.	.
1644	-3.87	-6.35	-6.46	-2.52	.	.	.	.
1645	-3.32	-4.14	-5.10	-1.74	.	.	.	.
1646	3.51	3.38	2.61	1.20	.	.	.	.
1647	3.89	4.73	5.17	0.46	.	.	.	.
1648	-2.83	-3.21	-3.08	-2.07	.	.	.	.
1649	0.40	4.72	5.78	4.93	.	.	.	.
1650	0.70	6.51	10.87	8.81	.	.	.	.
1651	3.11	2.43	1.97	0.15	.	.	.	.
1652	2.19	2.86	1.65	0.10	.	.	.	.
1653	-2.35	0.84	2.64	1.54	.	.	.	.
1654	-2.60	-2.12	-0.85	-0.67	.	.	.	.
1655	0.96	2.44	3.24	3.02	.	.	.	.
1656	-0.41	0.94	1.26	-0.07	.	.	.	.
1657	-2.23	-0.64	-0.01	-0.44	.	.	.	.
1658	0.35	2.17	2.75	2.45	.	.	.	.
1659	0.15	-1.76	-2.75	-2.13	.	.	.	.
1660	1.72	0.78	1.33	3.04	.	.	.	.
1661	3.64	0.84	-1.91	-2.13	.	.	.	.
1662	0.05	0.44	0.44	0.72	.	.	.	.
1663	-0.20	-0.87	-1.02	-0.17	.	.	.	.
1664	-2.07	-4.39	-3.44	-0.71	.	.	.	.
1665	0.65	0.82	0.76	1.46	.	.	.	.
1666	-3.01	-2.89	-3.39	-3.10	.	.	.	.
1667	-5.33	-0.87	0.55	-0.24	.	.	.	.
1668	-7.44	-0.72	3.94	3.03	.	.	.	.
1669	-3.01	-2.46	-2.01	-1.99	.	.	.	.
1670	-4.60	-2.39	-1.55	-1.45	.	.	.	.
1671	0.93	1.89	1.23	1.01	.	.	.	.
1672	-0.99	1.31	2.29	1.45	.	.	.	.
1673	-5.04	-2.93	-0.47	-0.32	.	.	.	.
1674	-0.67	1.05	0.64	-0.15	.	.	.	.
1675	-0.94	-1.86	-1.07	0.13	.	.	.	.
1676	-3.13	-3.44	-1.44	0.12	.	.	.	.
1677	2.56	4.49	5.13	4.31	.	.	.	.
1678	0.61	0.33	-0.24	-1.15	.	.	.	.
1679	1.68	1.05	-0.24	-0.59	.	.	.	.
1680	4.41	4.06	2.63	1.95	.	.	.	.
1681	1.75	-0.47	-1.00	-0.11	.	.	.	.
1682	2.60	-0.75	-2.45	-0.89	.	.	.	.
1683	3.89	2.85	1.26	1.77	.	.	.	.
1684	-0.28	-0.85	-1.07	-0.91	.	.	.	.
1685	-4.64	-3.58	-1.84	-1.11	.	.	.	.
1686	2.18	1.80	3.09	4.59	.	.	.	.
1687	0.04	-0.78	-0.07	0.33	.	.	.	.
1688	-3.34	-1.08	1.17	1.32	.	.	.	.
1689	3.05	2.08	0.66	0.36	.	.	.	.
1690	3.88	0.11	-1.98	-0.88	.	.	.	.
1691	-1.11	-3.02	-4.91	-3.93	.	.	.	.
1692	3.39	1.18	-2.42	-1.43	.	.	.	.
1693	2.86	3.93	3.01	2.38	.	.	.	.
1694	-0.07	1.36	3.89	3.88	.	.	.	.
1695	1.51	6.13	8.41	5.53	.	.	.	.
1696	-4.57	-1.94	1.87	0.84	.	.	.	.
1697	-0.27	-0.38	1.97	2.87	.	.	.	.
1698	-0.76	-1.63	0.23	1.41	.	.	.	.
1699	1.71	-1.36	-2.04	-0.41	.	.	.	.
1700	2.15	1.16	-0.41	-0.25	.	.	.	.
1701	4.82	3.54	2.33	2.63	.	.	.	.
1702	-0.04	1.34	1.10	-0.50	.	.	.	.
1703	0.24	-1.27	-2.48	-2.27	.	.	.	.
1704	-3.30	-4.03	-4.32	-3.26	.	.	.	.
1705	-4.33	-4.23	-4.01	-2.56	.	.	.	.
1706	-1.04	0.80	1.16	1.63	.	.	.	.
1707	-1.78	-1.01	-0.52	-0.40	.	.	.	.

Table A11 (Cont'd)

YEAR	RTX5	RTX6	RTX7	RTX8	OTX5	OTX6	OTX7	OTX8
1708	-1.85	-1.52	-0.77	-0.09	.	.	.	.
1709	-4.97	-4.43	-3.18	-2.08	.	.	.	.
1710	1.43	0.16	-1.38	-0.06	.	.	.	.
1711	-1.06	-1.53	-1.58	-0.47	.	.	.	.
1712	1.07	0.48	-1.06	-1.03	.	.	.	.
1713	0.04	-0.10	-0.11	0.44	.	.	.	.
1714	-2.70	-4.78	-5.52	-4.12	.	.	.	.
1715	-4.78	-5.56	-6.37	-4.06	.	.	.	.
1716	-5.42	-7.71	-6.06	-1.29	.	.	.	.
1717	-0.17	-0.61	-3.48	-3.25	.	.	.	.
1718	3.60	6.38	3.49	1.56	.	.	.	.
1719	-1.96	4.39	8.38	6.42	.	.	.	.
1720	0.73	3.00	5.46	3.86	.	.	.	.
1721	4.93	5.77	5.52	3.45	.	.	.	.
1722	5.65	2.72	0.37	-0.49	.	.	.	.
1723	3.67	5.39	5.60	3.94	.	.	.	.
1724	1.80	1.09	-0.05	-1.31	.	.	.	.
1725	-1.18	-0.99	-0.61	-0.47	.	.	.	.
1726	7.88	5.68	3.19	3.21	.	.	.	.
1727	3.99	2.76	2.35	1.71	.	.	.	.
1728	-2.41	-3.16	-2.07	-1.51	.	.	.	.
1729	-1.63	-1.07	-1.39	-1.22	.	.	.	.
1730	-5.24	-5.56	-5.10	-3.44	.	.	.	.
1731	-3.84	-3.78	-3.78	-2.21	.	.	.	.
1732	-2.75	1.05	2.94	2.82	.	.	.	.
1733	-5.22	-0.20	4.35	3.43	.	.	.	.
1734	1.63	1.76	1.22	0.20	.	.	.	.
1735	1.74	3.21	3.25	2.63	.	.	.	.
1736	1.78	-0.82	-2.98	-2.89	.	.	.	.
1737	3.80	1.86	-0.30	0.27	.	.	.	.
1738	1.30	-0.45	-2.58	-2.75	.	.	.	.
1739	-4.49	-0.56	1.64	1.14	.	.	.	.
1740	-1.19	2.18	5.93	6.17	.	.	.	.
1741	0.25	-2.76	-2.44	-1.04	.	.	.	.
1742	-4.11	-5.44	-4.35	-1.90	.	.	.	.
1743	-1.11	-2.91	-4.29	-2.50	.	.	.	.
1744	0.55	0.06	-0.90	0.30	.	.	.	.
1745	3.00	1.81	-0.36	-0.41	.	.	.	.
1746	7.25	6.18	2.73	1.47	.	.	.	.
1747	7.14	6.46	2.43	-0.17	.	.	.	.
1748	-3.59	0.76	3.67	1.97	.	.	.	.
1749	-2.28	-0.47	0.84	0.11	.	.	.	.
1750	-1.88	-3.15	-4.28	-3.55	.	.	.	.
1751	0.24	-1.54	-4.11	-3.06	.	.	.	.
1752	-4.91	-4.58	-3.78	-2.25	.	.	.	.
1753	-2.71	-0.46	0.26	0.48	.	.	.	.
1754	-1.11	-0.48	-1.80	-2.47	.	.	.	.
1755	-1.81	-3.07	-3.55	-2.22	.	.	.	.
1756	-1.31	0.49	1.45	1.88	.	.	.	.
1757	-6.07	-1.98	2.40	2.48	.	.	.	.
1758	0.47	2.62	4.89	4.43	.	.	.	.
1759	2.90	2.18	2.39	1.94	.	.	.	.
1760	-0.27	-1.18	-0.93	-0.68	.	.	.	.
1761	2.33	2.02	0.91	0.86	.	.	.	.
1762	3.83	2.84	2.98	3.53	.	.	.	.
1763	-2.45	-2.75	-0.08	1.14	.	.	.	.
1764	0.36	-0.98	-0.75	0.22	.	.	.	.
1765	-0.05	-0.07	-1.21	-1.33	.	.	.	.
1766	5.01	3.17	1.24	1.85	.	.	.	.
1767	1.83	0.98	0.95	1.31	.	.	.	.
1768	2.47	1.46	0.55	0.28	.	.	.	.
1769	3.29	1.73	-0.46	-0.70	.	.	.	.
1770	3.86	3.33	1.71	0.89	.	.	.	.
1771	2.38	1.73	0.72	0.04	.	.	.	.
1772	-0.45	-1.08	-1.01	-0.97	.	.	.	.
1773	-3.54	-1.20	0.28	-0.05	.	.	.	.
1774	-2.29	-0.35	0.94	0.69	.	.	.	.
1775	1.57	-0.40	-1.76	-1.42	.	.	.	.
1776	-0.38	-2.47	-4.15	-3.05	.	.	.	.
1777	-2.30	-3.97	-4.38	-2.00	.	.	.	.
1778	-2.96	-3.11	-3.37	-1.97	.	.	.	.
1779	-1.37	2.10	2.87	2.20	.	.	.	.
1780	-2.66	-2.15	-0.66	-0.17	.	.	.	.
1781	-2.31	-2.29	-1.51	-0.75	.	.	.	.
1782	-3.18	0.75	2.75	2.33	.	.	.	.
1783	2.33	1.11	0.53	0.87	.	.	.	.
1784	5.37	2.78	1.97	2.89	.	.	.	.
1785	-2.43	-5.11	-4.42	-2.81	.	.	.	.
1786	-4.65	-6.34	-6.03	-3.14	.	.	.	.
1787	-0.91	0.79	-0.45	-0.45	.	.	.	.
1788	1.69	3.66	3.39	2.55	.	.	.	.
1789	-5.04	-5.82	-4.46	-3.46	.	.	.	.
1790	-5.20	-5.57	-6.19	-4.81	.	.	.	.
1791	0.85	1.92	-2.68	-4.05	.	.	.	.
1792	2.28	5.28	3.87	2.23	.	.	.	.
1793	5.97	7.05	5.90	3.60	.	.	.	.
1794	3.23	1.95	2.29	1.98	.	.	.	.
1795	4.55	3.56	2.24	1.30	.	.	.	.
1796	-0.92	1.08	2.25	1.36	.	.	.	.
1797	-1.35	0.48	2.24	1.84	.	.	.	.
1798	-1.14	-1.14	-1.38	-1.68	.	.	.	.
1799	1.76	4.49	4.18	2.85	.	.	.	.
1800	0.51	0.31	0.92	0.92	.	.	.	.
1801	-2.12	-2.93	-1.09	0.51	.	.	.	.
1802	-0.05	-0.08	1.28	2.53	.	.	.	.
1803	-1.49	0.77	4.23	4.58	.	.	.	.
1804	-1.21	0.58	2.21	1.25	.	.	.	.
1805	-4.96	-5.28	-4.60	-3.85	.	.	.	.
1806	-2.98	-4.87	-6.67	-4.53	.	.	.	.
1807	-1.86	-0.74	-0.67	0.84	.	.	.	.
1808	-5.24	-2.86	-1.89	-1.98	.	.	.	.
1809	-0.58	0.87	2.10	2.93	.	.	.	.
1810	0.16	2.60	2.65	1.16	.	.	.	.
1811	0.59	0.99	3.52	4.09	.	.	.	.
1812	-2.31	-1.60	1.59	2.19	.	.	.	.
1813	-4.48	-3.23	-0.20	0.81	.	.	.	.
1814	0.13	2.58	4.22	3.96	.	.	.	.
1815	3.23	2.00	0.43	-0.22	.	.	.	.
1816	8.58	4.79	1.78	2.35	.	.	.	.
1817	1.81	0.98	1.65	2.16	.	.	.	.
1818	-4.84	-1.23	1.40	0.62	.	.	.	.
1819	-5.76	-4.20	-2.34	-1.83	.	.	.	.
1820	-4.44	-4.04	-3.73	-2.50	.	.	.	.
1821	3.46	3.64	0.11	-0.79	.	.	.	.
1822	-0.24	-0.77	-0.79	-0.38	.	.	.	.
1823	-2.14	0.14	1.68	1.09	.	.	.	.
1824	0.80	-1.17	-2.39	-1.86	.	.	.	.
1825	2.60	2.40	0.48	0.06	.	.	.	.
1826	4.31	0.94	-1.17	-0.27	.	.	.	.
1827	8.66	3.83	-0.41	-0.14	.	.	.	.
1828	3.83	1.63	0.54	1.05	.	.	.	.
1829	4.87	4.01	1.28	-0.13	.	.	.	.
1830	1.39	0.48	0.72	1.00	.	.	.	.
1831	-1.79	-0.44	0.52	-0.16	.	.	.	.
1832	-1.98	1.19	1.62	-0.13	.	.	.	.
1833	3.83	4.60	4.31	3.43	.	.	.	.
1834	3.32	2.46	1.55	0.71	.	.	.	.
1835	2.94	-0.14	-2.75	-2.64	.	.	.	.
1836	0.17	0.04	-0.21	0.39	.	.	.	.
1837	2.96	0.80	0.01	0.88	.	.	.	.
1838	0.40	-0.24	-0.70	-0.53	.	.	.	.
1839	1.18	-0.22	-1.00	-0.30	.	.	.	.
1840	-0.83	-1.43	-2.45	-2.21	.	.	.	.
1841	-3.90	-4.67	-4.47	-2.83	.	.	.	.

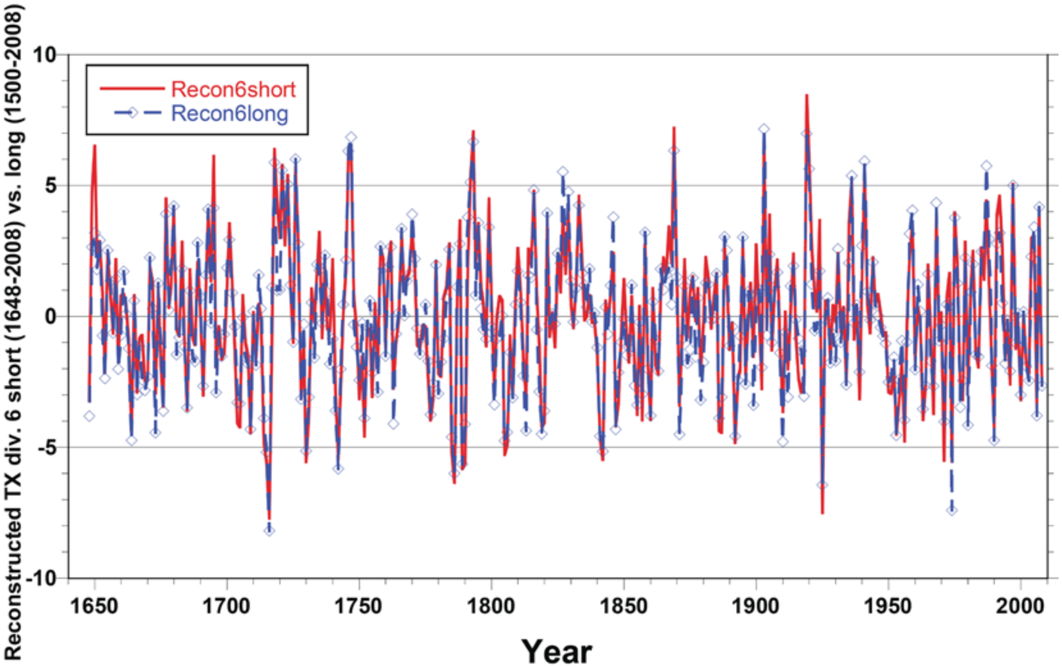
Table A11 (Cont'd)

YEAR	RTX5	RTX6	RTX7	RTX8	OTX5	OTX6	OTX7	OTX8
1842	-4.77	-5.48	-4.83	-2.44	.	.	.	.
1843	-0.03	0.59	-0.42	0.26	.	.	.	.
1844	1.58	-0.19	-0.29	1.39	.	.	.	.
1845	3.19	0.83	-0.68	0.01	.	.	.	.
1846	5.01	2.42	-1.31	-1.66	.	.	.	.
1847	-4.67	-4.19	-3.07	-2.07	.	.	.	.
1848	-1.29	-3.30	-4.65	-2.96	.	.	.	.
1849	-0.40	-0.73	-2.08	-0.90	.	.	.	.
1850	1.86	1.43	1.09	2.24	.	.	.	.
1851	-2.08	-0.73	-0.03	-0.37	.	.	.	.
1852	-0.56	-1.76	-2.23	-1.41	.	.	.	.
1853	2.57	0.78	-0.98	-0.11	.	.	.	.
1854	-3.44	-1.66	0.11	0.61	.	.	.	.
1855	-0.74	-3.76	-3.51	-0.99	.	.	.	.
1856	3.03	0.39	-1.26	0.75	.	.	.	.
1857	0.28	-3.97	-6.58	-4.71	.	.	.	.
1858	5.39	2.73	-1.05	-0.00	.	.	.	.
1859	-2.50	-1.77	-1.63	-1.45	.	.	.	.
1860	-4.91	-3.94	-2.73	-1.88	.	.	.	.
1861	-3.23	1.08	3.13	2.57	.	.	.	.
1862	-4.07	-1.83	-0.97	-2.13	.	.	.	.
1863	-5.41	-2.20	-1.61	-2.40	.	.	.	.
1864	-3.36	0.79	-0.07	-2.28	.	.	.	.
1865	-0.64	2.24	3.39	3.15	.	.	.	.
1866	-0.06	1.60	2.61	1.56	.	.	.	.
1867	-1.21	3.42	6.80	5.41	.	.	.	.
1868	1.63	2.05	2.98	2.13	.	.	.	.
1869	4.97	7.19	7.65	5.46	.	.	.	.
1870	0.62	1.75	3.60	2.14	.	.	.	.
1871	-2.35	-3.40	-2.39	-1.40	.	.	.	.
1872	-3.13	-0.52	0.77	0.48	.	.	.	.
1873	-0.15	2.18	3.27	2.76	.	.	.	.
1874	-2.19	-0.79	1.36	1.37	.	.	.	.
1875	-2.39	0.91	4.66	4.59	.	.	.	.
1876	1.44	1.53	1.69	0.70	.	.	.	.
1877	0.29	-0.17	-0.30	0.17	.	.	.	.
1878	0.26	1.08	1.10	0.83	.	.	.	.
1879	-2.90	-2.12	-0.57	0.16	.	.	.	.
1880	-3.38	-0.37	1.31	0.96	.	.	.	.
1881	2.36	2.27	1.36	1.21	.	.	.	.
1882	3.46	1.45	0.69	1.33	.	.	.	.
1883	1.85	-0.46	-1.29	-0.52	.	.	.	.
1884	0.22	0.75	2.17	2.72	.	.	.	.
1885	1.30	1.66	2.79	2.72	.	.	.	.
1886	-4.05	-4.34	-2.53	-1.81	.	.	.	.
1887	-3.33	-4.44	-4.40	-2.88	.	.	.	.
1888	3.57	2.64	0.92	1.70	.	.	.	.
1889	1.70	1.44	0.68	0.08	.	.	.	.
1890	-2.93	-1.26	1.08	1.07	.	.	.	.
1891	1.95	-0.25	-1.93	-1.24	.	.	.	.
1892	-4.10	-4.82	-4.09	-2.37	.	.	.	.
1893	-2.76	-2.36	-1.20	0.43	.	.	.	.
1894	-3.16	-2.05	-1.36	-1.41	.	.	.	.
1895	-0.88	2.80	3.89	2.40	4.81	2.78	2.91	2.10
1896	0.08	-2.21	-2.32	-1.01	-1.34	-2.16	-2.05	-1.93
1897	0.14	0.08	-0.35	-0.23	-0.13	0.86	-0.98	-1.67
1898	1.03	1.27	1.02	1.22	0.72	0.52	-0.67	0.70
1899	-1.69	-1.55	0.85	2.47	0.36	1.16	1.84	1.47
1900	-2.35	2.75	6.79	5.85	0.57	3.21	3.05	2.81
1901	2.39	0.18	-1.71	-2.45	-1.51	-2.02	-1.28	-0.98
1902	-1.26	-2.76	-3.15	-2.09	-2.88	-3.74	-3.80	-3.14
1903	4.81	6.58	3.82	1.66	2.83	3.26	3.27	2.02
1904	-3.92	-0.49	0.95	-0.76	-2.02	-0.78	0.56	0.44
1905	3.36	3.88	5.37	6.07	2.60	4.65	3.91	3.40
1906	2.62	-1.29	-3.41	-2.94	-1.01	2.88	2.42	-0.78
1907	2.06	0.99	-1.13	-0.62	-1.33	-0.22	-0.54	-0.70
1908	5.95	2.16	-1.26	0.04	-1.16	0.00	-0.40	1.34
1909	-1.66	-1.23	-1.16	-1.10	-2.68	-2.92	-3.21	-1.83
1910	-5.90	-3.65	-1.18	-0.48	-2.76	-2.21	-2.22	-0.66
1911	-0.19	0.18	-0.54	-0.18	-0.39	-2.80	-3.39	-1.95
1912	-0.25	-2.01	-2.48	-0.58	-0.06	-0.76	-0.28	1.33
1913	0.48	0.25	-2.31	-2.77	1.12	-1.03	-0.40	0.31
1914	2.60	2.38	1.61	2.21	2.83	4.60	4.57	3.22
1915	2.73	-0.68	-2.41	-1.52	2.94	3.91	-1.08	-1.11
1916	-1.89	-2.37	-3.45	-3.37	-2.13	-2.30	-3.35	-3.30
1917	-0.22	-2.89	-4.51	-2.68	-2.89	-4.11	-5.34	-3.88
1918	-2.69	-2.35	-1.87	-0.22	-3.44	-4.65	-5.42	-4.47
1919	2.95	8.44	8.97	6.34	3.74	4.83	4.11	3.41
1920	5.44	6.15	5.05	2.10	3.42	4.79	3.79	2.32
1921	0.87	2.55	4.09	2.76	1.63	-0.03	0.97	0.74
1922	-2.78	0.95	5.17	4.23	0.61	2.54	2.74	2.43
1923	0.27	0.20	1.27	1.13	-0.93	-1.00	-0.96	1.04
1924	2.06	3.67	4.68	4.07	-0.77	3.30	0.02	-0.15
1925	-6.64	-7.51	-5.58	-4.77	-2.99	-4.56	-4.39	-4.75
1926	2.77	0.61	0.16	2.90	1.82	2.55	3.11	2.83
1927	1.72	0.45	-1.07	-0.96	-2.14	-1.13	-1.00	-0.07
1928	-0.07	-1.65	-1.93	-0.52	-1.94	-1.88	-2.08	-1.13
1929	-0.35	0.43	0.88	1.55	-0.79	-0.09	-0.32	-0.41
1930	-0.05	-0.21	0.62	1.57	-1.34	-0.03	-0.06	-0.77
1931	3.90	2.41	0.06	-0.30	5.33	4.29	-0.34	-1.05
1932	0.67	-0.57	-1.16	-0.31	1.70	1.87	-0.75	-0.82
1933	1.61	0.36	-1.17	-0.82	-0.42	-1.04	-1.99	-2.67
1934	-4.59	-2.58	-1.75	-1.97	-3.36	-2.81	-1.44	-1.21
1935	-2.08	3.55	7.45	6.85	-3.36	4.83	2.85	1.02
1936	2.65	5.22	5.67	2.58	-1.86	3.64	2.98	-0.67
1937	0.37	-0.87	-1.23	-1.66	-0.41	-0.48	-1.09	-1.75
1938	0.50	0.32	1.98	2.90	1.59	1.10	-0.16	-0.67
1939	-1.36	-3.15	-3.30	-2.53	-0.76	-3.23	-3.45	-2.02
1940	2.16	1.20	-1.69	-1.96	2.92	2.75	1.56	-2.01
1941	7.15	5.50	2.59	2.30	9.44	5.33	5.46	3.46
1942	5.82	0.48	-1.84	-0.70	4.18	-1.57	-1.70	2.09
1943	0.94	-0.62	-1.25	-0.64	0.65	-1.61	-1.73	-1.43
1944	1.66	2.25	1.65	1.16	-0.30	2.64	-0.15	-0.62
1945	0.49	0.49	1.26	1.32	-2.13	-0.35	0.17	0.51
1946	-0.85	0.85	2.74	2.65	-0.42	0.70	2.08	3.44
1947	0.16	0.07	0.76	0.90	-0.21	-0.26	-0.34	-0.21
1948	-1.05	-0.67	-1.06	-1.31	-2.56	-1.51	-1.66	-1.36
1949	1.19	-0.61	-0.83	0.94	2.00	2.70	-0.81	-1.23
1950	-3.16	-2.87	-2.25	-1.66	0.10	-0.81	-0.17	-0.12
1951	-2.44	-2.95	-2.61	-1.25	-1.87	-3.05	-3.45	-3.28
1952	-1.40	-2.03	-3.13	-2.17	-2.62	-3.23	-3.36	-1.70
1953	-4.94	-4.51	-3.33	-1.62	-4.17	-2.36	-2.47	0.63
1954	-6.38	-3.24	-1.53	-1.59	-2.57	-3.48	-3.86	-2.46
1955	-3.82	-1.78	-1.23	-1.34	-3.15	-4.19	-4.89	-3.46
1956	-4.77	-4.76	-4.97	-4.00	-3.64	-5.58	-5.89	-4.04
1957	-4.19	-0.39	1.95	2.43	-3.46	4.01	2.49	2.28
1958	0.37	2.33	1.33	-0.75	2.37	4.37	2.41	-1.76
1959	0.35	3.49	4.00	2.03	-0.94	2.46	2.16	1.51
1960	-1.62	-1.66	0.12	0.69	-1.34	0.79	1.68	1.61
1961	-1.06	0.33	0.24	-0.80	1.43	1.24	0.88	2.80
1962	-0.63	-0.17	-1.22	-1.65	-2.34	-2.43	-2.07	-1.23
1963	-0.88	-3.95	-5.58	-3.64	-1.74	-3.60	-4.11	-3.39
1964	-2.14	-2.62	-2.14	-0.19	-2.36	-2.64	-2.84	-2.73
1965	-1.42	1.96	2.63	1.65	-1.58	2.06	-0.02	-2.70
1966	-1.92	-0.59	0.93	1.02	1.03	-0.52	1.91	2.31
1967	-1.11	-3.72	-3.45	-1.59	-1.64	-4.33	-4.42	-3.07
1968	4.62	3.83	1.53	1.36	-1.33	2.81	4.75	3.22
1969	-1.56	-0.56	0.78	0.80	-0.64	1.46	3.08	-0.39
1970	1.25	0.14	-0.91	-0.65	2.17	-0.06	2.23	1.47
1971	-3.06	-5.50	-5.73	-3.91	-2.90	-3.51	-4.24	-2.86
1972	-0.87	0.75	1.20	1.92	0.89	0.54	2.29	0.61
1973	3.08	1.65	1.12	2.10	0.84	0.52	3.69	3.54
1974*	-7.52	-5.54	-1.66	-0.39	-3.09	-2.98	1.83	2.35
1975	1.07	3.96	3.27	1.82	5.31	3.57	2.56	1.50

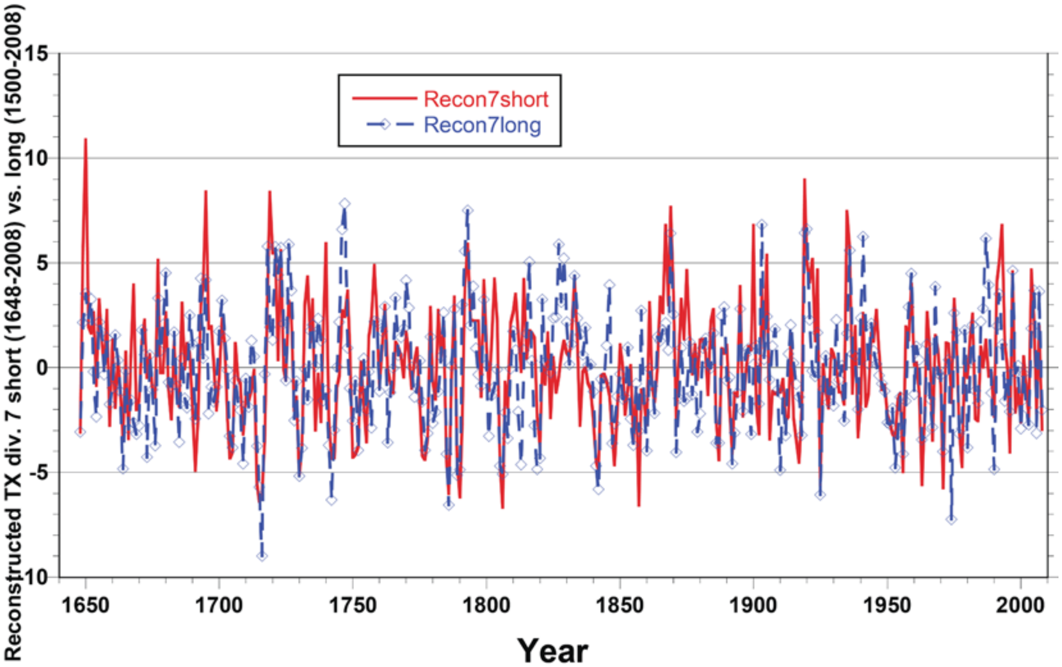
Table A11 (Cont'd)

YEAR	RTX5	RTX6	RTX7	RTX8	OTX5	OTX6	OTX7	OTX8
1976	0.42	2.02	1.25	-0.09	0.19	-0.53	1.50	0.58
1977	0.35	-2.47	-2.91	-1.02	-0.60	-0.24	-0.10	-0.32
1978	-0.98	-3.20	-4.74	-3.26	-1.69	-2.83	-1.83	-1.40
1979	4.40	2.85	0.31	1.34	3.53	1.66	3.06	2.24
1980	-2.28	-2.61	-0.48	1.24	-2.54	-2.08	-1.28	-0.66
1981	2.29	1.06	1.46	2.39	3.06	3.47	2.12	2.18
1982	2.55	2.50	2.57	2.41	-0.26	-0.16	-0.33	-0.21
1983	0.86	-1.35	-2.41	-1.95	-0.59	-0.18	1.03	1.52
1984	0.64	-1.95	-2.53	-0.46	1.70	-3.41	-2.29	-1.67
1985	4.09	2.62	0.99	1.44	0.45	0.30	1.88	-0.51
1986	1.99	1.41	0.02	-0.95	1.81	0.69	0.99	1.02
1987	6.53	4.42	1.31	0.64	8.35	5.28	4.04	2.43
1988	2.51	1.26	-0.41	-1.31	-1.53	-1.90	-1.60	-1.23
1989	-2.99	-1.84	-0.23	0.07	-2.12	-1.72	-2.52	2.17
1990	-5.55	-4.26	-2.34	-1.52	-3.44	-0.96	-3.06	-0.64
1991	2.23	3.85	4.14	4.15	1.07	0.24	1.85	3.46
1992	3.33	4.59	5.04	3.77	8.29	5.01	6.39	5.10
1993	-0.48	2.54	6.79	6.19	-1.51	-0.54	5.59	5.31
1994	-3.12	-1.57	1.23	0.49	-1.86	-1.83	-0.15	-0.09
1995	-2.11	-0.53	-0.05	-0.63	-2.04	0.87	2.05	2.48
1996	-1.41	-2.59	-4.02	-3.29	0.40	-3.82	-3.73	-1.80
1997	1.97	5.06	4.58	3.33	1.55	4.60	3.08	3.18
1998	-1.18	-1.22	-2.13	-3.06	-3.00	-2.35	-2.33	-2.12
1999	-1.49	-0.25	-0.98	-1.51	-1.95	-1.01	-0.36	-0.85
2000	-3.63	-3.18	-2.60	-1.63	-3.25	-3.89	-2.42	-3.11
2001	-1.13	0.03	0.52	0.80	-2.97	-1.35	-0.90	1.67
2002	-3.83	-1.81	-0.69	-0.91	-4.09	-2.22	-1.72	0.15
2003	-2.54	-2.15	-2.35	-1.70	-2.16	0.30	-1.70	0.00
2004	1.09	2.97	4.67	4.99	1.38	2.30	2.96	4.00
2005	3.43	3.08	2.10	0.60	3.60	2.50	-1.05	-1.25
2006	-2.21	-3.59	-2.17	-0.73	-3.77	-3.72	-4.95	0.51
2007	3.75	4.08	1.98	1.05	3.98	4.81	2.65	2.92
2008	-0.98	-2.63	-2.96	-2.00	-3.06	-2.97	-3.34	-1.59
2009	.	.	.	.	-0.88	-3.41	-5.85	-2.87
2010	.	.	.	.	1.35	1.98	2.55	-0.93
2011	.	.	.	.	-5.20	-5.10	-4.04	-3.95

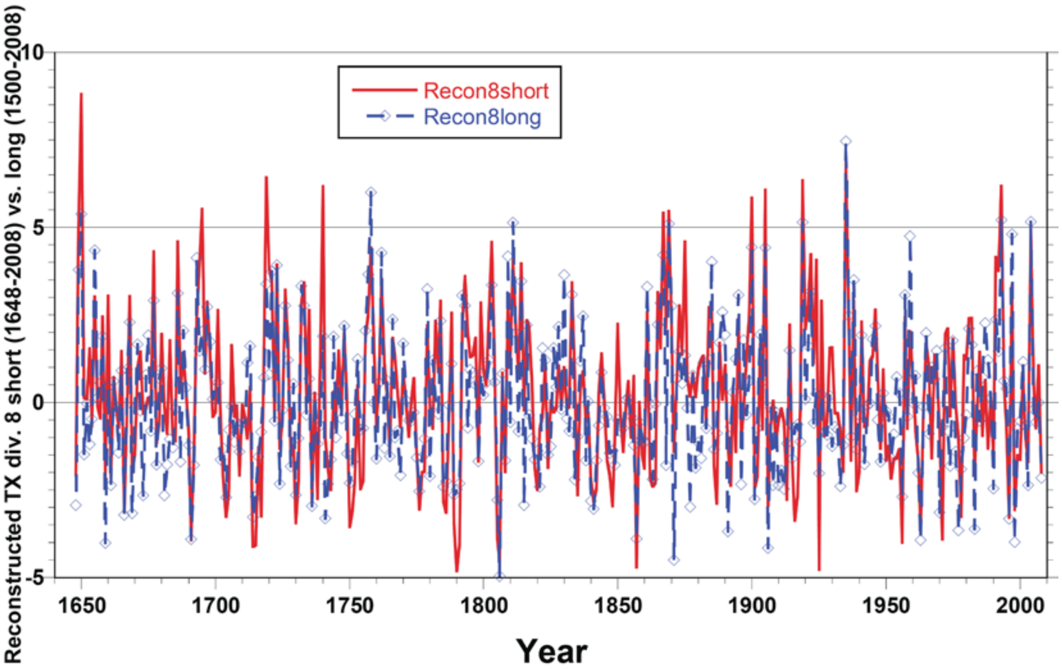
*June PDSI estimates for 1974 had a large amount of error, and were consistently more negative in all 4 divisions reconstructed than the observed values. See discussion of estimation error in general and for 1974 in particular on pages 68–71.



14. **Fig. A1.** Climate division 6 (Edwards Plateau), 2 reconstructions of June PDSI in the 1648–2008 overlap period. Blue is the long reconstruction (1500–2008) and red is the short reconstruction (1648–2008).



15. **Fig. A2.** Climate division 7 (S. Central), 2 reconstructions of June PDSI in the 1648–2008 overlap period. Blue is the long reconstruction (1500–2008) and red is the short reconstruction (1648–2008).



16. **Fig. A3.** Climate division 8 (Upper Coast), 2 reconstructions of June PDSI in the 1648–2008 overlap period. Blue is the long reconstruction (1500–2008) and red is the short reconstruction (1648–2008).