

PALEOCLIMATIC ANALOGS TO TWENTIETH-CENTURY MOISTURE REGIMES ACROSS THE UNITED STATES*

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Decadal drought and wetness regimes similar to the three major moisture anomalies witnessed across the United States during the twentieth century are identified in continent-wide tree-ring reconstructions for the past 500 yr.

Decadal drought and wetness extremes punctuated the twentieth-century climate over the central and western United States. A strong pluvial in the early twentieth century covered a large portion of the West and lasted for more than a decade. Severe, sustained droughts afflicted most of the United States in the 1930s and 1950s (Fig. 1a). These moisture regimes have had an enormous impact on the economy and environment of the United States. The early twen-

tieth-century pluvial-biased estimates of stream discharge in the Colorado River basin contributed to unrealistic allocation of Colorado River water in subsequent decades (e.g., Stockton 1975; Reisner 1986; Brown 1988). The Dust Bowl drought of the 1930s interacted with poor land-use practices and led to one of the greatest demographic migrations in American history (Steinbeck 1939; Reisner 1986). The 1950s drought had a severe environmental impact over the Southwest and Southern Great Plains, but its national economic impact was muted, in part because it occurred before the dramatic population redistribution associated with the post-World War II growth of the Sunbelt.

These decadal moisture regimes raise interesting questions about the degree of historical precedent in the paleoclimatic record. To what extent are they representative of large-scale decadal variability during the late Holocene? Recent tree-ring reconstructions of the summer Palmer Drought Severity index (PDSI; Palmer 1965) across the continental United States for the last 500 yr (Cook et al. 1996, 1999; and this paper) provide an excellent opportunity to search for decadal drought and moisture anomaly patterns in the

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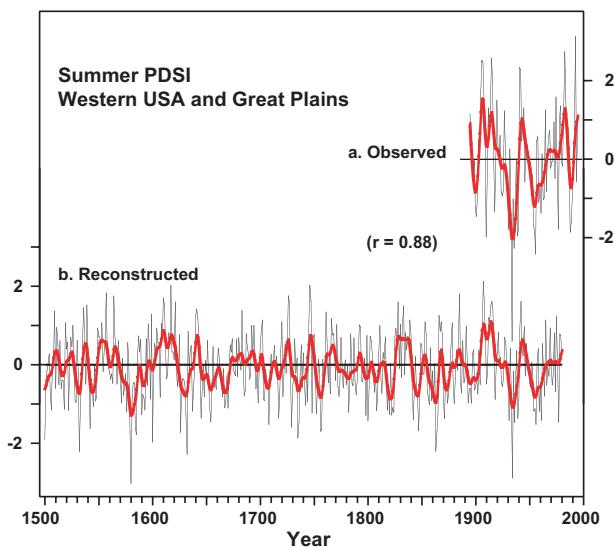


FIG. 1. (a) Time series of regionally averaged summer PDSI for the western United States and Great Plains derived from instrumental data for the period 1985–95 (Cook et al. 1996). A 10-yr spline was fit to the PDSI data to highlight dry and wet regimes. **(b)** Time series of reconstructed PDSI for the western United States and Great Plains, extending from A.D. 1500–1978 (Cook et al. 1996, 1999). Note the coherence of observed and reconstructed decadal moisture regimes, especially the early twentieth-century pluvial (1905–17), Dust Bowl (1929–40), and the 1950s drought (1946–56). The extraordinary drought of 1934, evident in both the observed and reconstructed data, was equaled or surpassed only by the incredible drought of 1580. The simple correlation between these two time series is 0.88. The correlation between the decadal smoothed splines is 0.92.

preinstrumental period (Fig. 1b). Our analyses indicate that the great decadal moisture regimes of the twentieth century, with the possible exception of the Dust Bowl drought, have had close analogs in terms of magnitude, duration, and location over the past 500 yr.

DATA AND METHODS. *Observed and reconstructed PDSI data.* Gridded reconstructions of summer PDSI over the continental United States were developed by Cook et al. (1996, 1999). These data were derived from annual proxies of drought and wetness provided by 426 climatically sensitive tree-ring chronologies (Fig. 2). The tree-ring data integrate a seasonal moisture signal across the United States that tends to be maxi-

mized during the June–August (JJA) period. The JJA seasonalization of PDSI was a compromise for the spatially variable phenological development of tree growth in response to the south-to-north march of the growing season. Instrumental PDSI were first gridded in a $2^\circ \times 3^\circ$ latitude–longitude scheme covering the conterminous United States. Nearby tree-ring chronologies were then used to reconstruct summer PDSI at each grid point using point-by-point regression [i.e., principal components regression analysis involving screening and autoregressive modeling of potential predictors with the predictor suite only including those chronologies in the vicinity of each grid point; see Cook et al. (1999)].

The interannual variations in summer PDSI were reconstructed with great fidelity when compared to the instrumental data in the calibration and verification periods (Cook et al. 1999). Over the entire 154 point grid, the median-squared correlation for the calibration period (1928–78) is 0.55 and over the validation period (pre-1928) is 0.36. Fewer instrumental stations and observations prior to 1928 contribute to the weaker validation statistics. When calibration and verification statistics are mapped, 50%–70% of the variance is explained by the regression models over large areas of the United States. The lowest verification statistics were observed in the Great Basin, where instrumental data quality is an issue, and the areas over North Dakota and western Kansas, where the coverage of tree-ring data is weak (Cook et al. 1999).

The decadal-scale fidelity of these tree-ring reconstructions is further confirmed by the spatial-tempo-

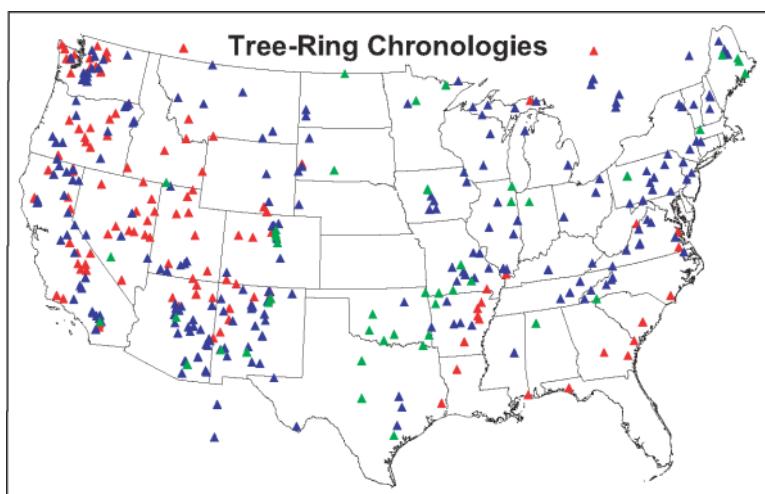


FIG. 2. Locations of 426 tree-ring chronologies used by Cook et al. (1996) to reconstruct summer PDSI. Some symbols represent multiple chronologies. All chronologies end in 1979 or later. Chronologies dating back to 1676 (green triangles), 1600 (blue triangles), and 1500 (or earlier) (red triangles).

ral analyses of instrumental and reconstructed summer PDSI reported below. It should be noted that fewer tree-ring chronologies are available prior to A.D. 1676, especially in the north and central High Plains, but coverage is adequate to derive useful estimates of PDSI over much of the southeastern, central, and western United States back to A.D. 1500.

Consecutive n -year composite analyses. Consecutive, n -year “decadal” averages of the summer of PDSI were used to show the strength and spatial extent of potential analogs to the three major moisture anomalies of the twentieth century (the early twentieth-century pluvial, Dust Bowl, and 1950s drought). We used a simple objective procedure to identify the likely start and end years of these decadal moisture regimes (we take decadal to be 6–21 yr). First, we identified three geographical footprints of the three twentieth-century moisture anomalies. The drought footprints for the Dust Bowl and the 1950s drought were identified from the gridded instrumental PDSI data points lying within the boundary of the -1 PDSI value (shown in Figs. 5a and 6a, respectively; for the pluvial, we used the $+1$ PDSI contour of Fig. 4a). All grid points within these subregions were then averaged into a single annually resolved time series of summer PDSI, and a 10-yr cubic-smoothing spline was fit to each regionally reconstructed and instrumental time series (Fig. 3). Sustained positive (wet) and negative (dry) excursions of the spline were then used to identify the major drought and wetness regimes in the three specific regions affected by the decadal moisture anomalies.

To objectively define the exact start and end years of these decadal drought and wetness regimes, a cumulative filter consisting of a running sum was applied to each regional reconstruction in Fig. 3. We identified the beginning or end year of a moisture regime when it was preceded or followed by two consecutive years of opposite sign in the cumulative filtered time series. The accumulation of each time series was always reset to zero in the year

immediately following termination of a regime. The cumulative filter identified the same basic drought and wetness regimes indicated by the spline curves in Fig. 3, but was most helpful for “objectively” identifying the specific start and end years of a consecutive moisture regime. We note, however, that this objective method led to the occasional inclusion of years with opposite sign in the average PDSI over the region in question. The resulting decadal moisture regimes are mapped in Figs. 4–6, excluding very weak regimes as indicated by the spline curve and cumulative sums.

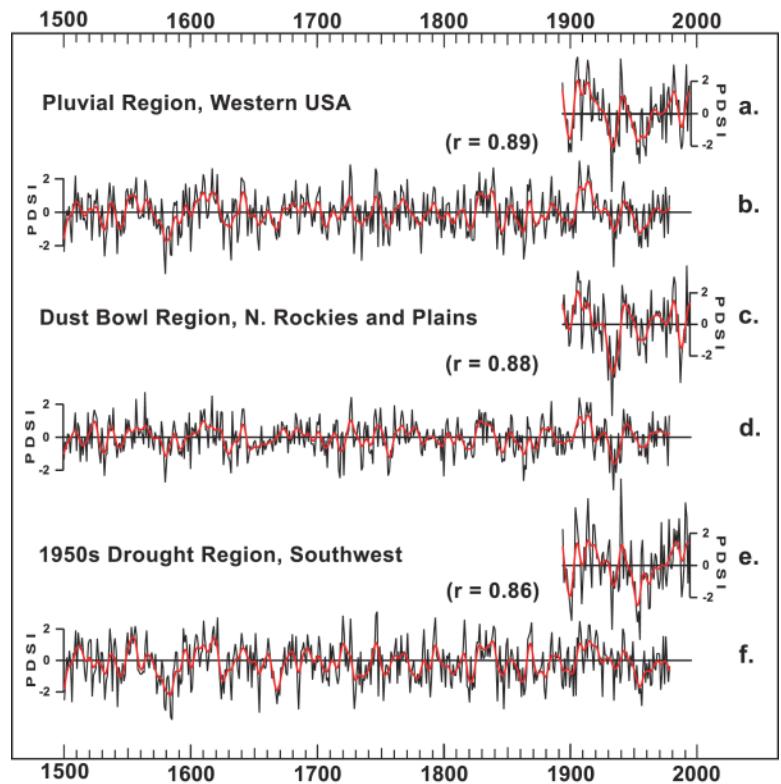


FIG. 3. (a) Instrumental summer PDSI from 1895 to 1995 for the western U. S. subregion impacted by the twentieth-century pluvial (i.e., the average of all grid points within the $+1.0$ isoline in Fig. 4a). (b) Same as (a), but for the reconstructed summer PDSI from 1500 to 1979 (using the grid points within the $+1.0$ isoline in Fig. 4b). (c) Instrumental summer PDSI from 1895 to 1995 for the subregion impacted by the Dust Bowl drought (the average of all grid points within the -1.0 isoline in Fig. 5a). (d) Same as (c), but for the reconstructed summer PDSI from 1500 to 1979 (using the grid points within the -1.0 isoline in Fig. 5b). (e) Instrumental summer PDSI from 1895 to 1995 for the subregion impacted by the 1950s drought (all grid points within the -1.0 isoline in Fig. 6a). (f) Same as (e), but for the reconstructed summer PDSI from 1500 to 1979 (using the -1.0 isoline in Fig. 6b). The simple correlations between the instrumental and reconstructed PDSI time series are listed for each subregion (based on the annually resolved data). A 10-yr smoothing spline was fit to all time series to highlight decadal variability (red line).

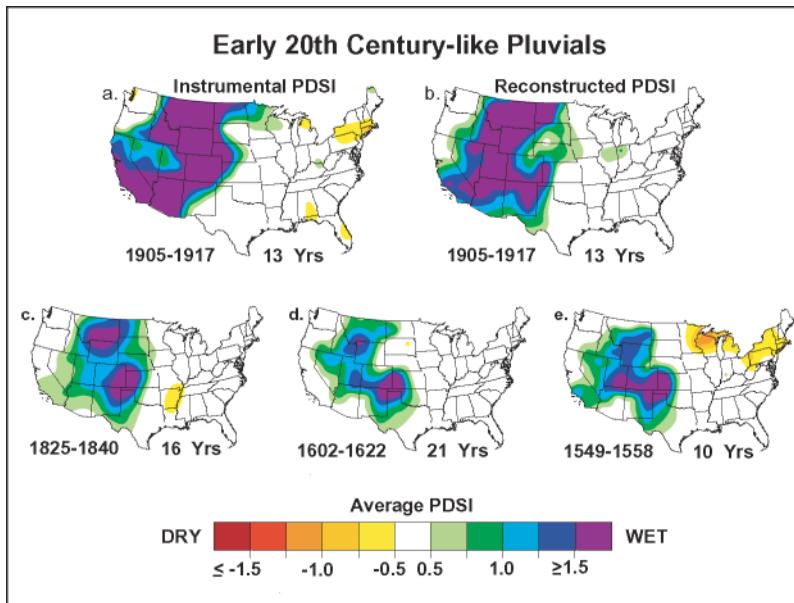


FIG. 4. The early twentieth-century pluvial and its analogs. (a) and (b) Mean instrumental and reconstructed summer PDSI for the period 1905–17; (c)–(e) Mean reconstructed summer PDSI averaged and mapped over the United States for the time periods indicated.

RESULTS. The greatest twentieth-century moisture anomalies across the United States were the 13-yr pluvial over the West in the early part of the century, and the epic droughts of the 1930s and 1950s, which by our calculations lasted 12 and 11 yr, respectively (Figs. 4a, 5a, 6a). The tree-ring data underestimate the absolute magnitude of the regimes, but they faithfully reproduce the history of drought and wetness, as well as the relative magnitude and broadscale spatial footprint of these regimes (Figs. 1b, 4b, 5b, 6b). For example, the early twentieth-century pluvial was the wettest episode, and the Dust Bowl and 1950s droughts were the first and second driest episodes from 1895 to 1978 in both the instrumental and reconstructed time series (Figs. 1a,b). Furthermore, the regionally averaged instrumental and reconstructed summer PDSI time series are very highly correlated (i.e., $r = 0.88$ for the entire western United States, $r = 0.89$ for the pluvial region, $r = 0.88$ for the Dust Bowl region, and $r = 0.86$ for the region most heavily impacted by the 1950s drought; see Figs. 1 and 3). We, therefore, argue that the tree-ring reconstructed maps of the twentieth-century pluvial (Fig. 4b), the Dust Bowl drought (Fig. 5b), and 1950s drought (Fig. 6b) can be used to guide the search for similar decadal moisture regimes witnessed across the United States during the last 500 yr.

Wet regimes similar to the twentieth-century pluvial. The twentieth-century pluvial (Figs. 3a, 4a) had a dramatic

impact on water resource planning and allocation in the semiarid American West, particularly in the Colorado River drainage system. The early misperception of water availability that was sufficient to meet the future needs of six western states led to overallocation of the Colorado's flow (Brown 1988) as part of the Colorado River Compact. The Compact was first negotiated in 1922 under the guidance of Commerce Secretary Herbert Hoover (Reisner 1986). When negotiations began among the interested states, the Reclamation Service provided an estimate of undeveloped flow at Lee's Ferry, Arizona, of at least 16.4 million acre feet per year (Hundley 1975). The signed Compact divided the flow at Lee's Ferry between the states of two artificial basins, the upper basin with 7.5 million acre feet and

the lower basin with 8.5 million acre feet [1.5 million acre feet was later added for Mexico (Brown 1988)].

Early tree-ring studies led E. Schulman to conclude that the wet conditions prevailing during the early twentieth-century were not representative of long-term variations in moisture supply over the West (Schulman 1956). Tree-ring reconstructions of the Colorado River streamflow have, in fact, estimated a 400-yr mean flow of only 13 million acre feet per year (Stockton 1975), compared with the Reclamation Service's earlier estimate of 16.5 million acre feet per year based on discharge records compiled primarily during the twentieth-century pluvial.

Because of disagreement over the proposed allocations, the Compact was not ratified until 1928, the same time the Boulder Dam was authorized (Reisner 1986). The Compact was flawed in that it was written in absolute terms for the water needs of 1922, without the flexibility of percentages apportionment to accommodate river-flow variability or changing demand (Brown 1988). The inflexibility of the Compact and the erroneous assumption of "abundant flow sufficient to meet all future needs" left a legacy of dispute and litigation over the water resources of the Colorado. As urbanization and irrigation place greater demands on the Colorado's waters, contention for this limited and variable resource will likely continue (Brown 1988).

The time series average of summer PDSI in the pluvial region (Fig. 3a) indicates that the prolonged

twentieth-century pluvial (1905–17) had three potential analogs in the nineteenth, seventeenth, and sixteenth centuries. An extended wet period lasted 16 yr from 1825 to 1840 over much the same region as the twentieth-century pluvial (Fig. 4c), and appears to have had major environmental and historical impacts. West (1995) cites historical accounts that describe the central High Plains region as lush grassland teeming with bison during this period.

A prolonged 21-yr pluvial is reconstructed for the western United States from 1602 to 1622 (Figs. 3a, 4d). This episode appears to have been wettest over the southern High Plains and over the Yellowstone region (Fig. 4d). Scurlock (1998) quotes Fray Benavides describing New Mexico in 1621 near the end of this pluvial, stating, “the abundance of game appears infinite.” One of the largest flood events evident in the marine varved sediment record from the Santa Barbara basin (southwest California) has been dated to approximately 1605 (Schimmelmann et al. 1998), and may represent one component of the early seventeenth-century pluvial. In fact, extreme wetness is reconstructed in our analysis for southern California and the drainage basin of the Ventura and Santa Clara Rivers in 1604 and 1605, even though the full 21-yr-long pluvial was focused over the Rockies and southern Plains (Fig. 4d).

A 10-yr pluvial reconstructed from 1549 to 1558 (Fig. 4e) occurred just before the most severe and widespread drought estimated for North America over the past 500 yr (Meko et al. 1995; Stahle et al. 2000). This pluvial clearly separates the sixteenth-century megadrought (1570–87; Fig. 6n) from the shorter intense drought dating from 1542 to 1548 (Fig. 6o) over the United States. However, the pluvial of 1549–58 does not appear to have penetrated southern Arizona and southwestern New Mexico. The available tree-ring evidence suggests that the sixteenth-century megadrought may have persisted with little relief from 1541 to 1580 across northern and central New Mexico (Stahle et al. 2000, 2002).

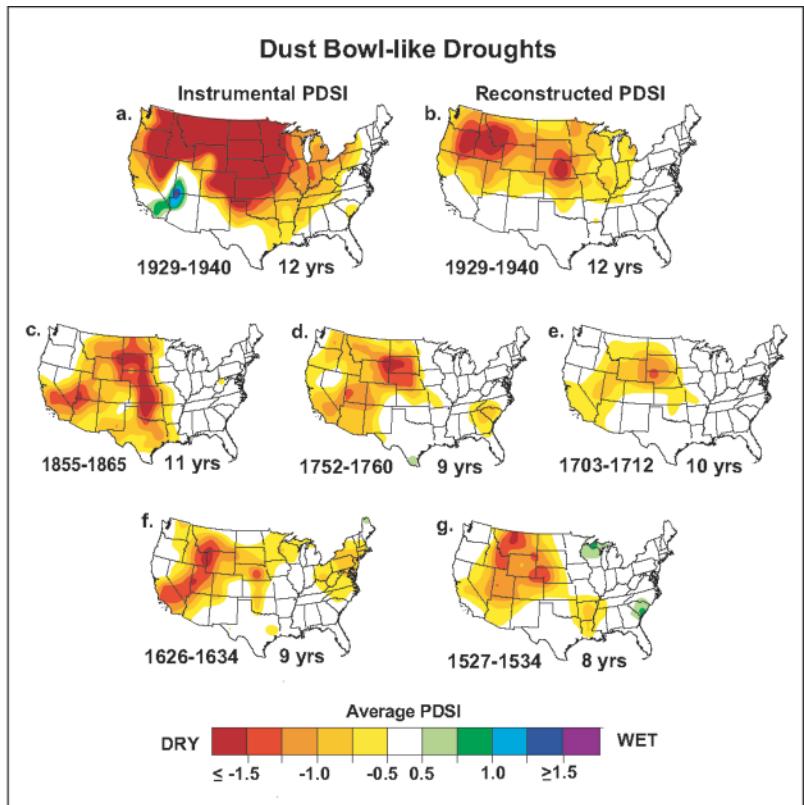


FIG. 5. The Dust Bowl drought of the 1930s and its analogs. (a) and (b) Mean instrumental and reconstructed summer PDSI for the period 1929–40; (c)–(g) reconstructed summer PDSI averaged and mapped for the drought periods shown. Note that two dry intervals objectively identified as possible Dust Bowl analogs (1815–24 and 1645–71) were omitted because they were primarily focused over the southwestern United States (see Figs. 6g and 6l).

Dust Bowl-like droughts. The Dust Bowl drought of the 1930s was the most severe sustained drought to impact the central and western United States during the period of instrumental observation (Fig. 1a). The Dust Bowl was also the worst drought to impact the country in terms of intensity, duration, and coverage since A.D. 1700, based on analyses of the 154 reconstructed grid points during the time period fully covered by all 426 tree-ring chronologies (Cook et al. 1999). The drought of 1934 was the single worst year of drought estimated for the continental United States by Cook et al. (1999) since 1700. In our analyses, 1934 is also estimated to have been the worst single year of drought coverage and intensity in 300 yr, and over the past 500 yr it may have been exceeded only by the extraordinary drought of 1580 (see Fig. 1b; Hughes and Brown 1992).

The economic and environmental impact of the Dust Bowl drought was aggravated by land-use practices across the Great Plains. Years of abundant rainfall associated with the early twentieth-century plu-

vial, followed by additional above-average PDSI during the parts of the 1920s, helped promote wheat cultivation on “millions and millions of acres” of what was once short-grass prairie (Reisner 1986). The sentiment of the day was “Get something growing—something more productive than pasture! Cash was what we wanted!” (Johnson 1947). Intensive cultivation of Great Plains grasslands left them vulnerable to drought and wind erosion.

The first signs of the epic Dust Bowl drought began in 1928 with unusually light snowfall in the Dakotas that fell on plowed fields waiting for the sowing of profitable wheat. The first small dust storms came in 1932 and increased in frequency in 1933. In November of 1933 a large storm blew across South Dakota, stripping topsoil from farms and creating huge drifts of silt. More storms followed in 1934, and in May soil swept from the plains of Montana and

Wyoming turned the skies black. Strong winds transported an estimated 350 million tons of topsoil eastward toward urban America. On 9 May 1934, “dust was falling like snow” in Chicago, Illinois. Over the next 2 days dust fell over Buffalo, New York; Boston, Massachusetts; New York, New York; Washington, D.C.; and even Atlanta, Georgia (Worster 1979).

The worst year for dust storms may have been 1935, epitomized by the 14 April Palm Sunday storm known as “Black Sunday.” This particular storm was etched in the memory of many Dust Bowl residents, some of whom believed the apocalypse had begun. The day began clear and fresh, but by midafternoon an immense black cloud and a 40° temperature drop had consumed Dodge City, Kansas, and then swept across the High Plains of Texas and New Mexico (Worster 1979). Daylight turned into utter darkness; it hurt to breathe, dust penetrated everything—beds, furniture, even food in the refrigerator (Johnson 1947). After 1935, the dust storms became more or less “routine” and remaining residents learned how to endure the choking, incessant dust. Dust storms continued into 1941 (Worster 1979).

Had the land remained short-grass prairie, the topsoil would likely have survived the ravages of this epic drought. But by 1934, the worst year of the drought, the National Resources Board estimated soils on 35 million acres were destroyed and another 125 million

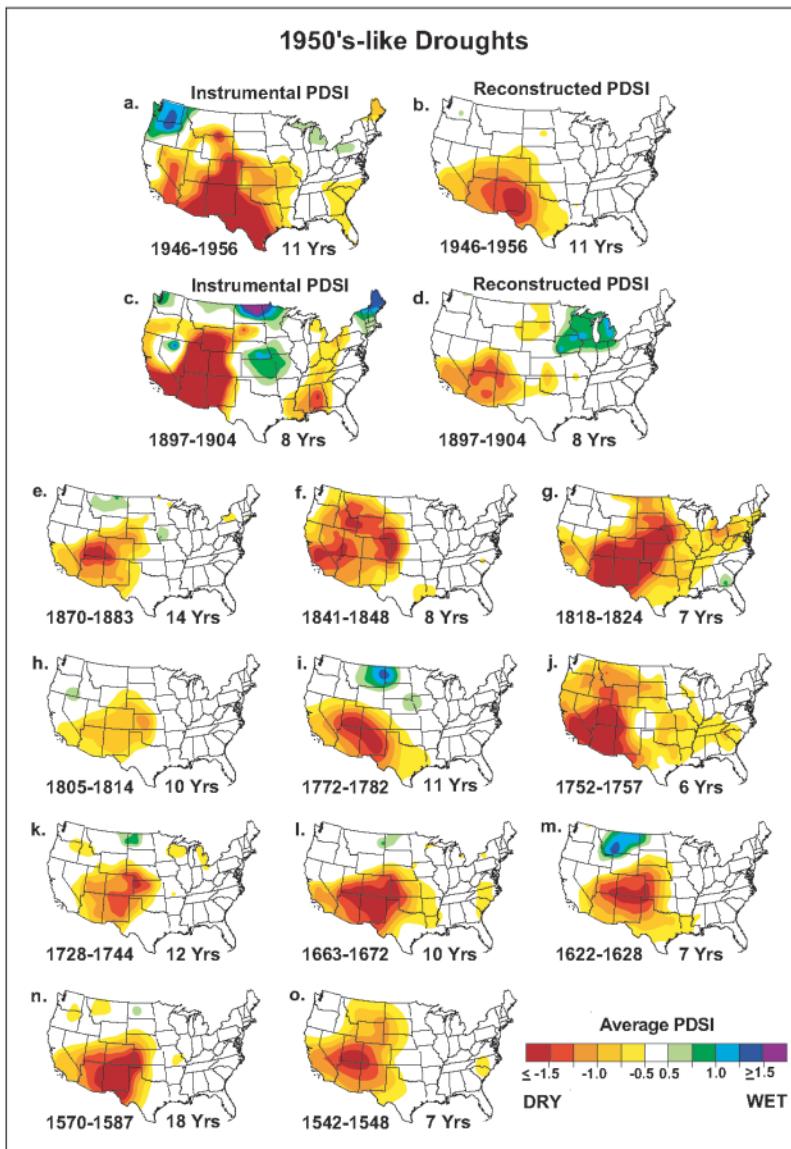


FIG. 6. The 1950s drought and its potential analogs. Mean instrumental and reconstructed summer PDSI for the period (a) and (b) 1946–56 and (c) and (d) 1897–1904. (e)–(o) Reconstructed summer PDSI is also mapped for 11 preinstrumental 1950s-like events for the time periods indicated. The dry period seen in Figs. 3d and 3f from 1855 to 1865 was objectively identified as both a 1950s and Dust Bowl analog (Fig. 5c) because of its spatial focus in the central and northern Plains.

acres were debilitated (Reisner 1986). The human toll was equally severe with a mass exodus of people and their belongings from the Great Plains. The states of North and South Dakota lost 146,000 people (Reisner 1986), and the luckless Okies made their famous trek to California (Steinbeck 1939).

Careful examination of the patterns of decadal drought over the past 500 yr has failed to reveal any strong analogs for the regional coverage, intensity, and duration of the Dust Bowl drought (Fig. 5b). The closest candidates are illustrated in Figs. 5c–g, but all exhibit important differences. Perhaps the two most similar events would have been the 9-yr drought from 1752 to 1760 (Fig. 5d) and the 8-yr drought from 1527 to 1534 (Fig. 5g). Both events resemble the spatial footprint of the Dust Bowl drought, but they do not fully replicate the duration and intensity of the epic 1930s drought. In fact, only the sixteenth-century megadrought, extending over 18 yr from 1570 to 1587 (Fig. 6n), appears to have equaled or exceeded the magnitude and duration of the Dust Bowl drought (Fig. 5b). Spatially, the Dust Bowl drought was focused over the central and northern Great Plains and northern Rockies (Figs. 5a,b) while the sixteenth-century megadrought was most severe over the southwestern United States and northern Mexico.

Droughts like the 1950s. The 11-yr drought from 1946–56 was the second worst drought to impact the United States during the instrumental period (Fig. 1a), and had a geographical focus across the southwestern portion of the country (Fig. 6a). Historical accounts of this drought indicate that it began over New Mexico in 1950 (Scurlock 1998), and illustrate the ambiguity involved in identifying the onset and termination of moisture regimes. For our analysis, we have adopted a strictly objective procedure that indicates onset of the 1950s drought in 1946 and termination in 1956. Examination of the instrumental PDSI for each year indicates that 1946 and 1947 were years of significant drought over the Southwest, 1948 recorded drought over the extreme Southwest and southern California, and 1949 was actually wet across the Southwest. But this single year of wetness occurred within a regime of decadal drought, and by 1950 drought over the Southwest was fully established.

The 1950s drought was the most severe Southwestern drought since weather records began in this region in 1895. The drought forced expanded use of irrigation and water tables dropped with the heavy pumping of groundwater (Fleck 1998). Intensive irrigation saved agriculture in areas with sufficient groundwater, but farmers relying on surface water

were widely forced out of business. Many ranchers in New Mexico had to sell livestock prematurely at very low prices (Scurlock 1998).

The primary sources of moisture in the 1950s drought region are winter snows and summer thunderstorms, but both sources declined dramatically during drought onset. The drought peaked in 1956, the last and driest year of this long 11-yr drought. Reservoirs in New Mexico were dry or very low, and as much as 60% of New Mexico's crops failed during this year. Cold fronts passing through the Albuquerque area in the spring of 1956 brought gusty winds and severe dust storms reminiscent of the Dust Bowl (Scurlock 1998). The forests and grasslands of New Mexico are well adapted to frequent drought, but the persistence of this drought led to mortality of range grasses, conifer woodlands, mesquite, and cacti on a massive scale (Fleck 1998; Swetnam and Betancourt 1998). In western Texas, there was significant mortality of range grasses that may have contributed to widespread brush invasion (Neilson 1986).

There appear to have been at least 12 other droughts since A.D. 1500 that were analogous to the 1950s drought in terms of location, intensity, and duration (Figs. 6c–o). The droughts of 1818–24 and 1841–48 (Fig. 6f) affected the Plains states as well as the Southwest, and bracketed a significant western pluvial (Fig. 4c) described by West (1995). Our analysis identifies large-scale drought regimes in 1841–48 (Fig. 6f) and 1855–65 (Fig. 5c), part of a midnineteenth-century period of mostly dry conditions over much of the western United States. In fact, eastern Colorado was persistently dry through this entire period from 1841 to 1865, especially from 1845 to 1856 (Woodhouse et al. 2002). As reviewed by Woodhouse et al. (2002) these midnineteenth-century droughts may have contributed to the demise of the great bison herds of the central High Plains by the 1860s (West 1995).

The sixteenth-century megadrought lasted some 18 yr and the tree-ring data indicate it was the most severe sustained drought to impact North America in the past 500 to perhaps 1000 yr (Fig. 6n; Stahle et al. 2000). The open isolines of PDSI on the international border (Fig. 6n) indicate that the sixteenth-century megadrought extended into Mexico as substantiated by new tree-ring chronologies from Durango and Puebla (Stahle et al. 2002). The human impact of the megadrought must have been extraordinary with abandonment and migration in New Mexico (Schroeder 1968), possible colonial impacts in the southeastern United States (Stahle et al. 2000), and famine and epidemic disease in Mexico (Acuna-Soto

et al. 2002). The recurrence of a drought as severe and sustained as the sixteenth-century megadrought would be devastating to the now heavily populated borderlands of Mexico and the southwestern United States (Stahle et al. 2000).

DISCUSSION. The PDSI reconstructions analyzed in this study provide interesting insight in the natural rhythm of decadal drought and wetness across the central and western United States (Fig. 1b). The long and precisely dated tree-ring records are excellent proxies of PDSI, and the twentieth-century tree-ring reconstructions closely match the spatial patterns of decade-scale moisture regimes actually witnessed in the instrumental record (Figs. 4a,b; 5a,b; 6a,b). The tree-ring reconstructions of summer PDSI faithfully reproduce the relative severity of the great twentieth-century pluvial, Dust Bowl, and 1950s drought. In fact, the tree-ring reconstructions reproduce much of the finescale structure of instrumental drought and wetness regimes, more so than is apparent with the isopleth scheme used in Figs. 4, 5, and 6. For example, during the Dust Bowl the driest conditions were observed and reconstructed for Nebraska and Montana (not evident in the isopleths used for instrumental PDSI; Fig. 5a).

This analysis indicates that the early twentieth-century pluvial (1905–17) was one of four intense, long-lasting, and widespread wet episodes over the Great Plains and western United States in the past 500 yr (Fig. 1b). In fact, the twentieth-century pluvial appears to have been the most extreme wet episode in the past 500 yr (Fig. 3b), but longer-duration pluvials occurred in the nineteenth and seventeenth centuries (Figs. 3 and 4). The tree-ring data suggest that these decadal wet episodes have indeed been rare with 200 yr separating the decadal pluvials reconstructed for the seventeenth and nineteenth centuries (Fig. 3b).

The reconstructions indicate that the Dust Bowl drought was one of the worst decadal droughts over the western United States in the past 500 yr, second only to the sixteenth-century megadrought (Fig. 1b). The 12-yr Dust Bowl drought had a geographical focus over the central-northern Great Plains and northern Rockies (Figs. 5a,b) and severe decadal droughts have been less frequent in this region than over the southwestern United States (Figs. 3d,f, 5, and 6). A few droughts similar to the Dust Bowl are evident in the tree-ring data (Fig. 5), but none seem to have fully equaled or exceeded the magnitude, duration, and geography of the Dust Bowl event.

Twelve 1950s-like droughts have been identified in this objective analysis of decadal drought, suggest-

ing a drought return period of about 45 yr. The 1950s drought was equaled or exceeded by droughts in the 1770s, 1660s, 1620s, and by the sixteenth-century megadrought (1570–87), which in this analysis lasted for 18 yr and appears to have been the worst drought over the United States in the past 500 yr (Figs. 6i,l,m,n).

Decadal drought was particularly common over the Southwest in the nineteenth century (64 yr from 1801 to 1900 were included in drought regimes; Figs. 5c, 6d–h). Only the long pluvial of 1825–40 (Fig. 4c) interrupted this nineteenth-century pattern of long-lasting drought. The relatively high frequency of 1950s-like droughts over a sector of the United States known to be influenced by El Niño–Southern Oscillation (ENSO) suggests that cold conditions in the eastern equatorial Pacific, perhaps coupled with the low phase of the North Pacific Oscillation may contribute to the development and persistence of decadal drought over the Southwest and northern Mexico (Gershunov and Barnett 1998).

The 1950s-like drought of 1897 to 1904 (Figs. 3e,f, and 6c,d) was more widespread in the instrumental than reconstructed data (Figs. 6c,d). Examination of the annual reconstructions between 1897 and 1904 reveals good agreement between the observed and reconstructed PDSI data for only 5 of the 8 yr. However, this is very early in the instrumental record, and some of the disagreement between observed and reconstructed PDSI may be attributed to the instrumental data. Note, for example, the improbable wet anomaly in the instrumental data for northern Nevada (Fig. 6c) within a large region of decadal drought.

The dendroclimatic record of the past 500 yr has been searched for close replicates of the decadal-scale moisture anomalies witnessed during the twentieth century. These gridded tree-ring reconstructions are a rich source of information on late-Holocene climatic variability over the United States. The network of moisture-sensitive tree-ring chronologies for North America has also recently grown with the contributions of many colleagues and now exceeds 600 chronologies extending from the boreal forest to the Tropics of southern Mexico. This outstanding array of exactly dated, annually resolved paleoclimatic proxies will soon be used to improve and expand the geographical coverage of PDSI reconstructions over North America.

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