Central Valley Droughts Over Last 1,000 Years

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BIOGRAPHICAL SKETCH

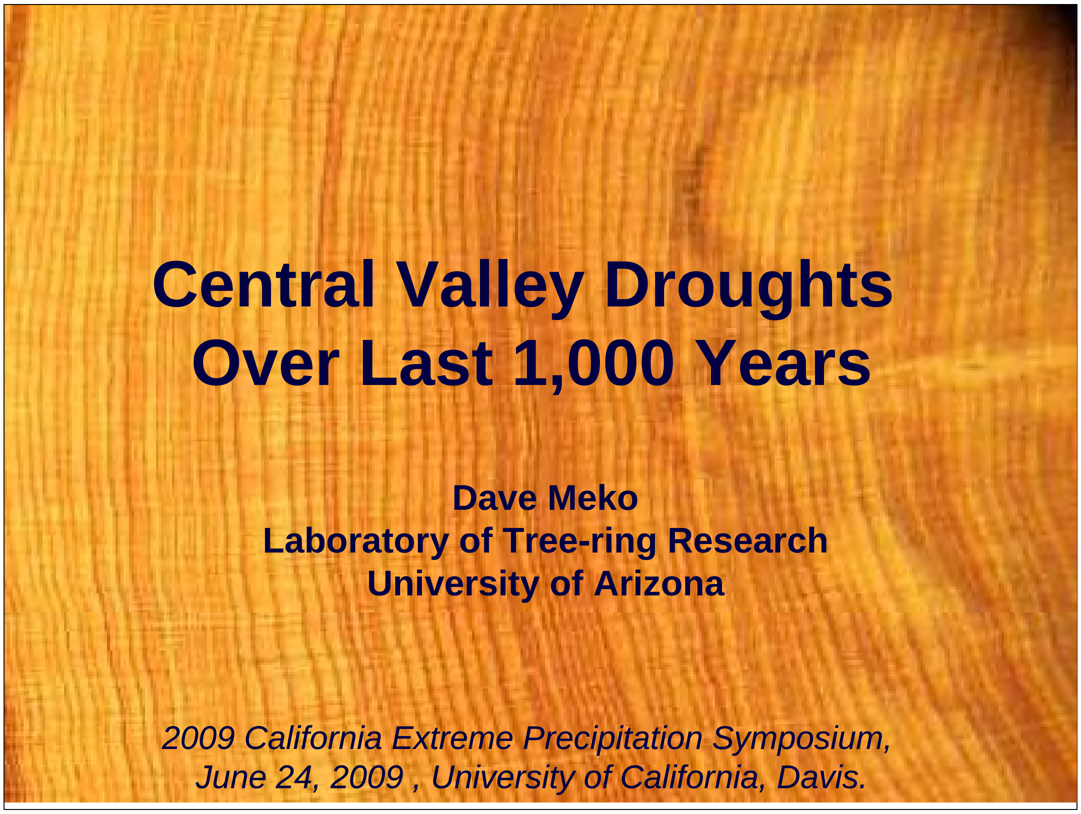
David Meko is an Associate Research Professor in the Tree-Ring Lab at the University of Arizona. He has advanced degrees in Hydrology and Atmospheric Sciences. He has published several papers applying tree rings to infer long-term variability of streamflow in the western United States. Study basins include the Colorado River, the Sacramento River in California, and the Salt, Verde and Gila Rivers in Arizona. Ongoing studies include application of tree-ring data to study the North American Monsoon, and developing ways to incorporate tree-ring reconstruction in river management models. Dr. Meko teaches an online course in time series analysis at the University of Arizona and co-teaches an international workshop on practical analysis of tree-ring data that was last held in the summer of 2008 in Istanbul, Turkey.

ABSTRACT

Severe hydrologic droughts can stress ecosystems, cut agricultural production and reduce available water resources for hydroelectric, industrial, municipal and other uses. Consequently, it is important to understand the natural variability of drought occurrence at various time scales, including those longer than amenable to study with relatively short gaged precipitation and streamflow records. The millennial timescale of drought variability in the Central Valley, California is addressed in this presentation. Available tree-ring reconstructions of annual flows of the Sacramento and San Joaquin rivers are summed and the two-river sum analyzed for information on hydrologic drought on annual to multi-decadal timescales. Droughts are tabulated by using moving averages over a reconstruction period from 942-1977 to place the post-1905 flows in a long-term context.

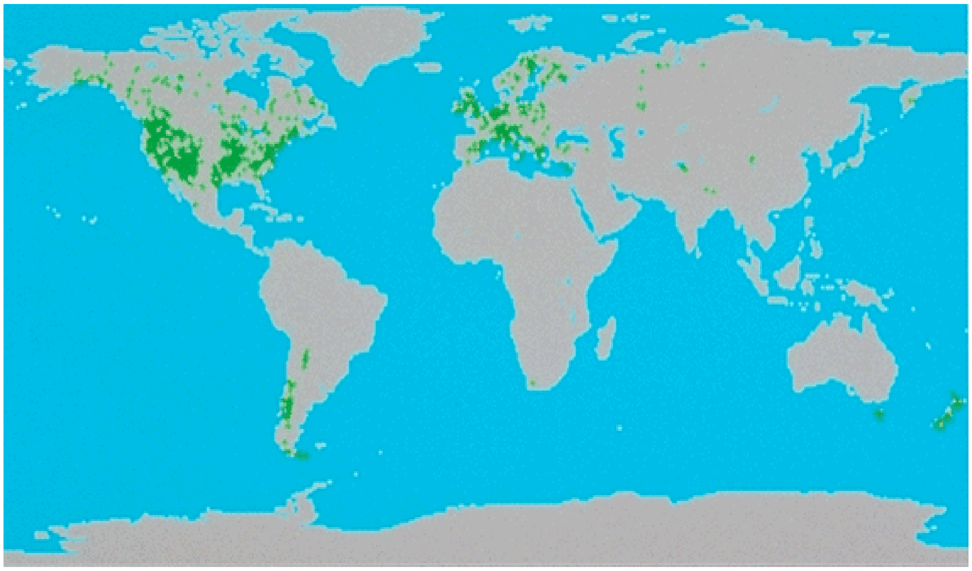
With the exception of a remarkable low-flow year in 1580, results show the period of gaged flows is fairly representative of worst-case single-year drought in the long-term record. For running means as long as six years the instrumental period likewise is a reasonable snapshot of long-term extremes: six-year droughts of the 1930s and 1980s-90s are as severe as any encountered in the tree-ring record. For longer running means the tree-ring record contains examples of drought severity and duration without analog since the start of the 20th century. For example, mean flow is reconstructed at 73 percent of normal (1906-2008 observed mean, 23.8x106 acre-feet) for the 25-year period ending in 1480. This is about 10 percent lower than any reconstructed 25-year mean in the 20th century. Tree rings indicate the 1400s drought was characterized by two pulses of severe drought imbedded in a longer period of 33 consecutive years with no annual flows exceeding 110 percent of normal.

A multi-decadal drought in the mid-1100s coincides with dry conditions identified by tree-ring studies in the Upper Colorado River Basin. Two of the most prominent high-flow peaks in 25-year running means are consistent with termination dates of previously identified low stands of Mono Lake. Planners in water resources, ecology and other fields should consider the possibility of recurrence of drought patterns similar to those in the tree-ring record. It should be emphasized that tree-ring reconstructions are imperfect recorders of precipitation and runoff, and that future collections of tree-ring data, especially in northern California, could lead to improved accuracy of reconstruction and revision of the drought history.



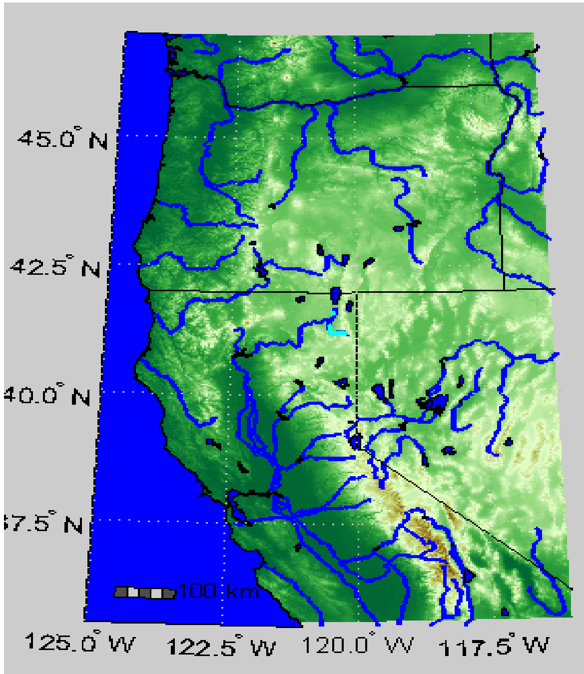
1. To understand the long-term variability in frequency and severity of drought we rely on proxy data.
2. Tree rings are especially useful for this purpose because of their annual resolution and long time span.
3. In this talk I draw on existing tree-ring reconstructions of streamflow to summarize some broad features of Central Valley droughts over the past 1000 years.

Tree-Ring Sites
International Tree-Ring Data Bank

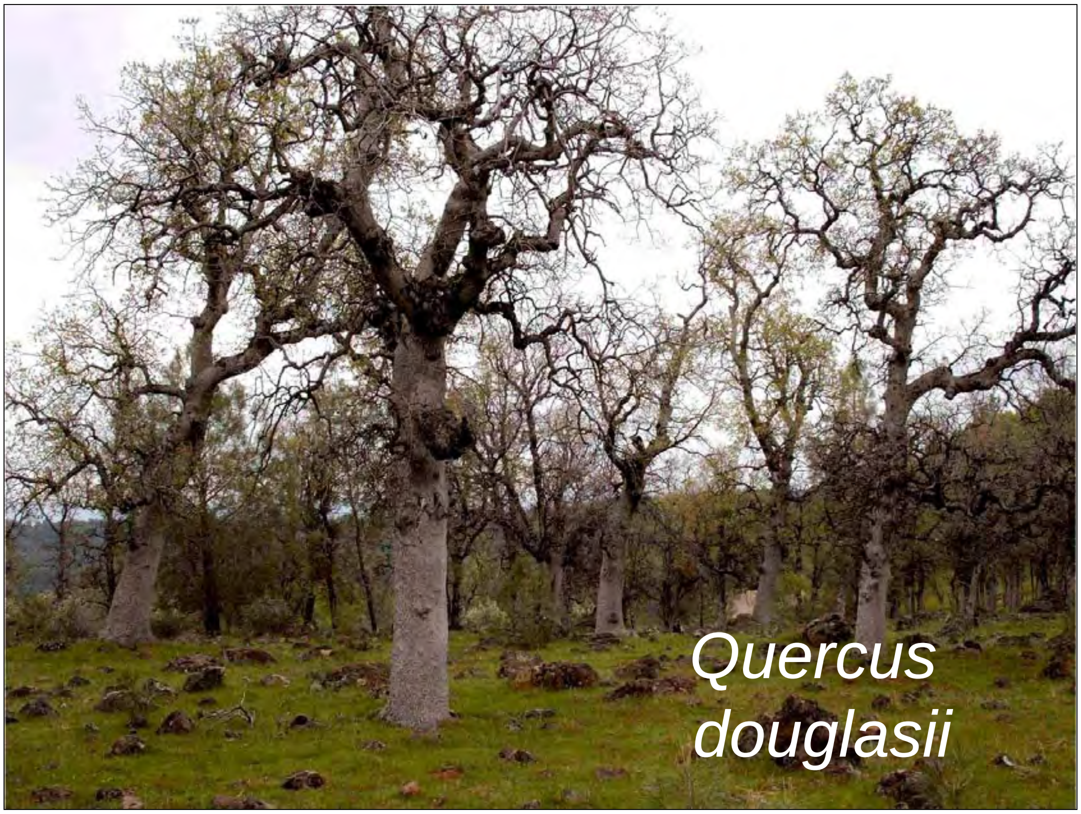


1. Tree-ring research in recent decades has resulting in an explosion of data development.
2. Site chronologies useful for climate studies are available for thousands of locations worldwide.
3. The western United States has long been a focal point of tree-ring collection.

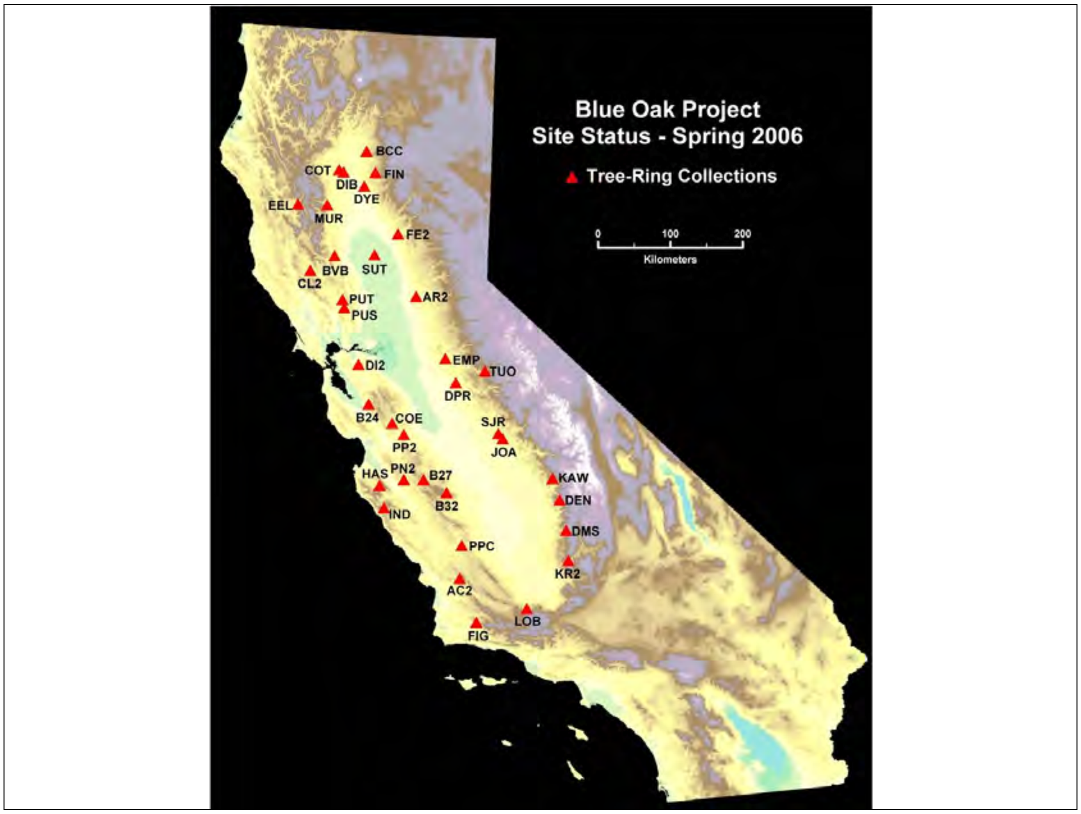
Central Valley: Several Useful Species



1. California has a rich tradition of tree-ring research.
2. The area around the Central Valley has several long-lived tree species useful for hydroclimatic studies.



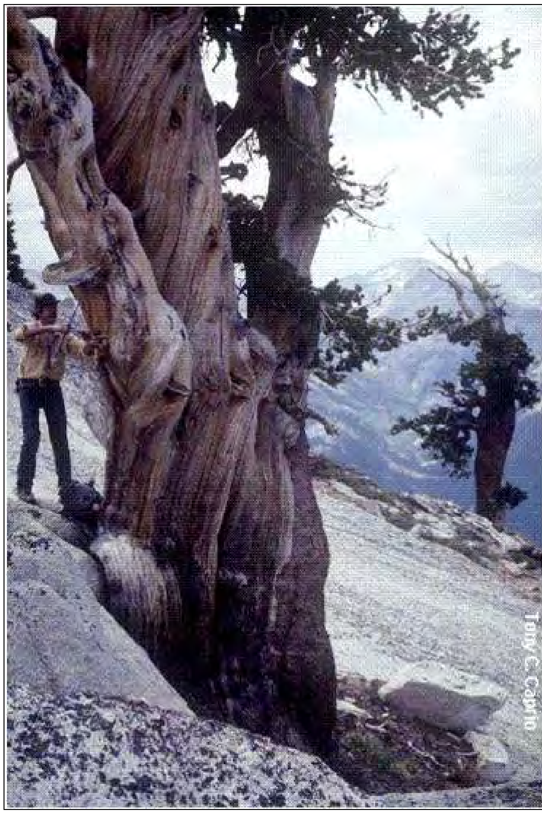
1. Blue oak is widely distributed in the region, and has perhaps the strongest cool-season precipitation signal of any tree-species in the U.S.
2. A shortcoming is perhaps tree longevity, which tops off at about 500 years.



1. Tree-ring collections by Dave Stahle at the University of Arkansas have yielded a network of some 36 blue oak sites in and around the Central Valley.
2. The potential of these data is just beginning to be exploited.

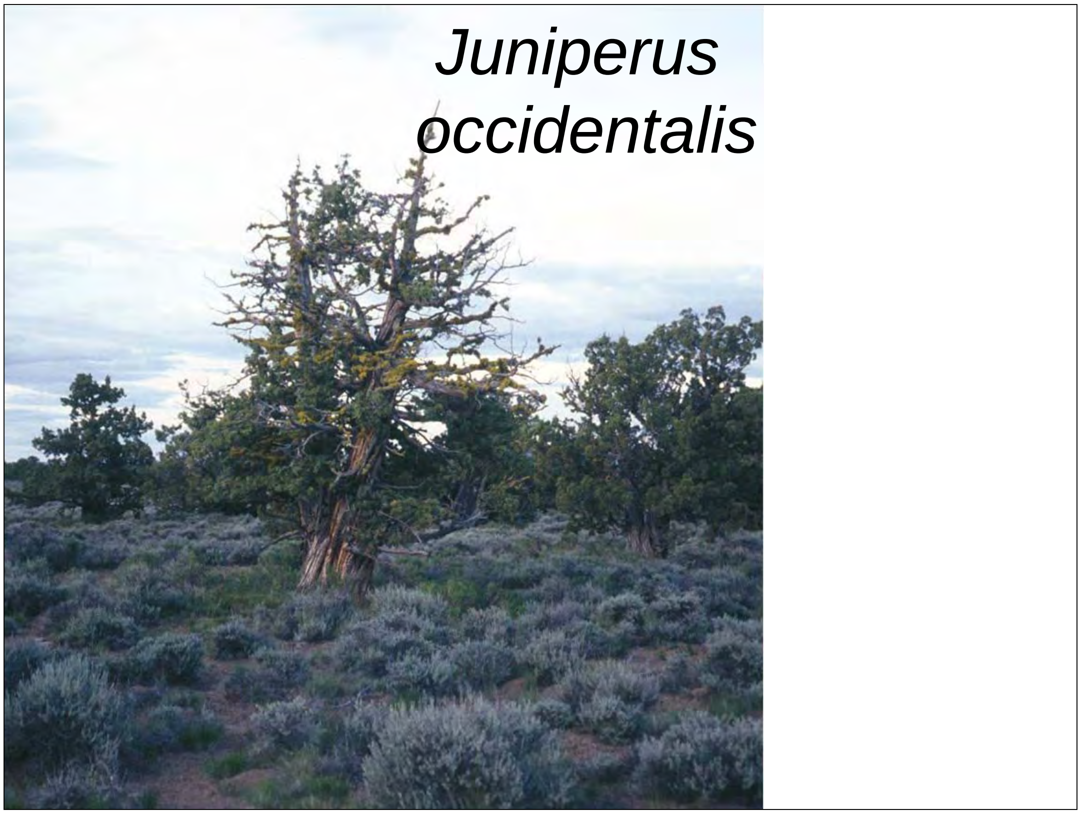
Sequoiadendron giganteum

1. Giant sequoia reaches much greater age than blue oak, but is restricted in distribution.
2. Fire effects on ring-width patterns have been a major complication for inferring drought history from sequoia.

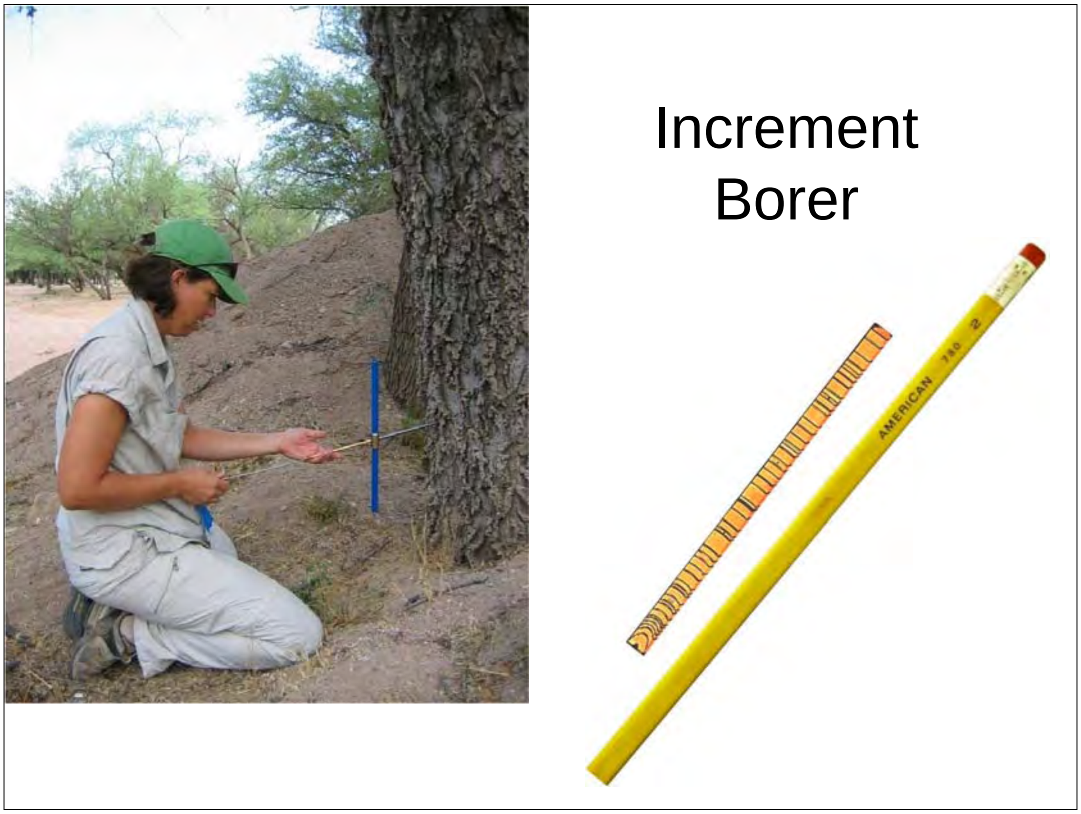


Pinus balfouriana

1. Foxtail pine is usually for the combination of great age and strong winter precipitation signal.
2. It's major shortcoming is a very restricted geographical range.



1. Western juniper is widely distribute in northern California, and in the high passes of the Sierra into central California.
2. Living juniper trees can exceed 1000 years in length, and in some locations have a strong precipitation signal.
3. Complications to its application to study winter precipitation in the Sierra Nevada include an amplified sensitivity to unusually moist conditions in May and June.
4. These are just a few of the tree species with potential for hydroclimatology.
5. Tree-ring reconstructions usually draw on multiple species.

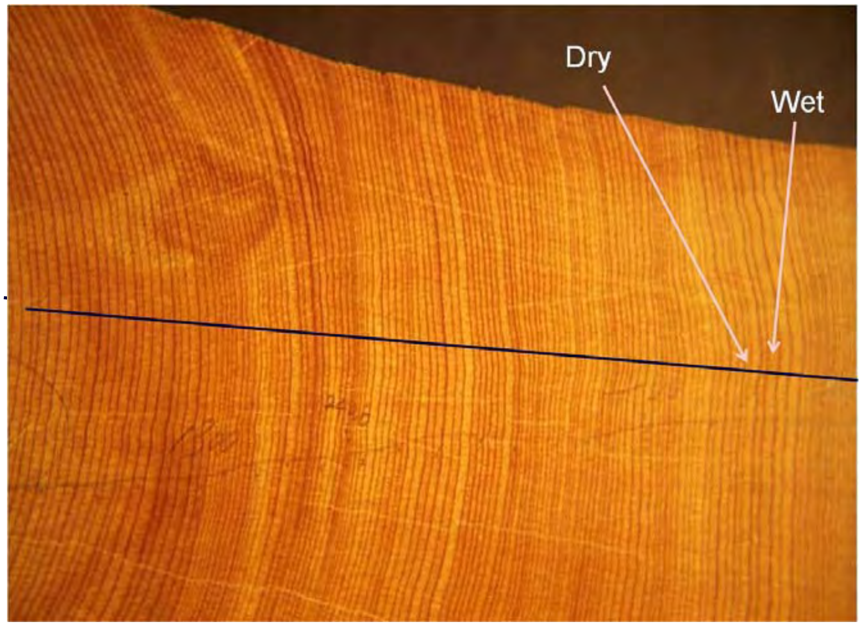


1. The most common sampling method in tree-ring collection is increment boring.
2. This method is non-destructive and yields wood samples thinner than pencil.

Chain Saw

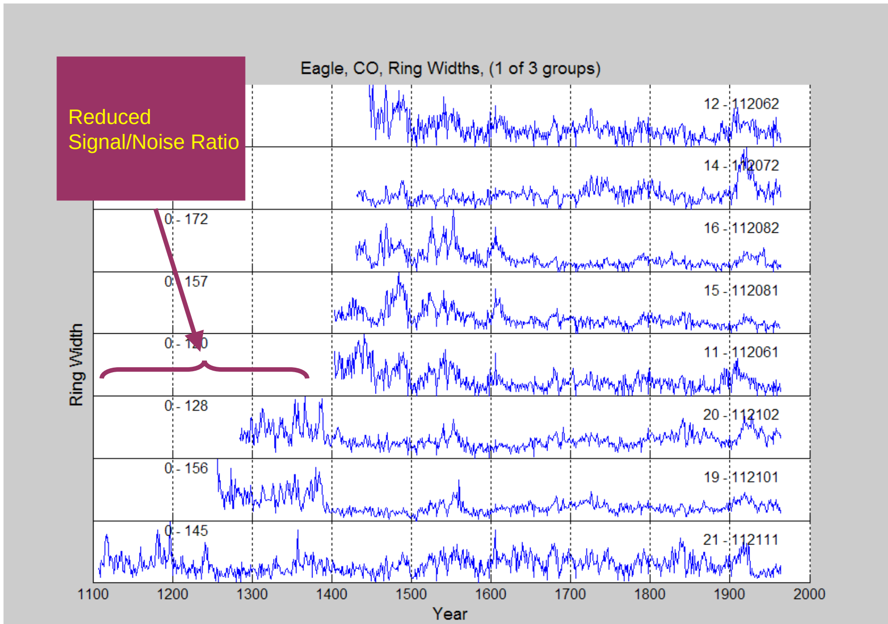
1. To extend climate records beyond the period covered by living trees we sample remnant wood.
2. Remnant wood is dead wood: stumps, standing snags and logs.
3. Depending on species and site, samples can be preserved on the surface for many centuries.
4. For these the sampling instrument is the chain saw.

Ring Width



1. Though tree-rings contain information in various chemical and physical properties, ring width is perhaps simplest to apply.
2. Rings of moisture-sensitive trees are wide in wet conditions and narrow in drought.

Replication & Standardization



1. Tree-ring studies rely on replication of samples.
2. Replication means as many trees as practically possible at a site, and multiple sites over a region or basin.
3. Tree ring chronologies are a mean value function– and average over trees.
4. The nature of the data is that the sample size will be smaller, and the chronology more uncertain, in the early centuries of the record.

Central Valley
Drought Chronology

Sacramento and San Joaquin Basins – regional hydrologic drought

Observed: Full natural flows, water years 1906-2008

Reconstructed.

Sacramento R. (2001 report for Calif. Dept Water Resources)

San Joaquin R. (2002 PACLIM Meeting, unpublished)

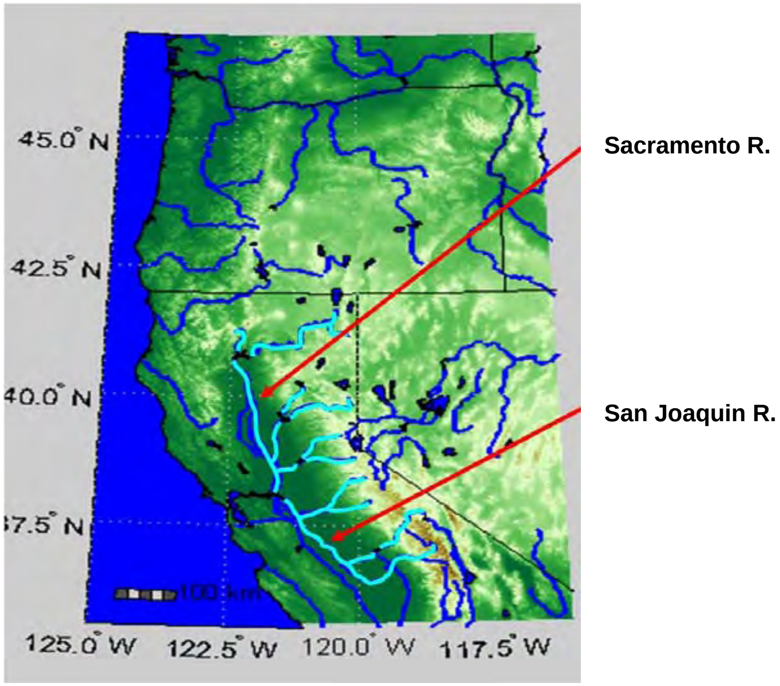
Two-river sum

1. Today I'll try to summarize some features of Central Valley drought history from selected existing tree-ring reconstruction.
2. Focus will be on the two-river sum (Sacramento and San Joaquin) of annual (water year) flow as a drought variable.

Meko, D. M. 2001. Reconstructed Sacramento River system runoff from tree rings. (Report prepared for the California Department of Water Resources under agreement No. B81923-SAP # 4600000193). Tucson, Arizona. Available from: California Department of Water Resources, P.O. Box 942836, Room 1601, Sacramento, CA 94236-0001.

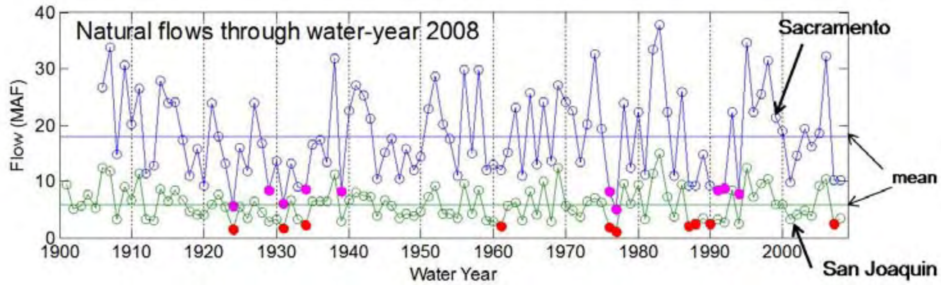
Meko, D. M., A. C. Caprio, R. Touchan, and M. H. Hughes. 2002. San Joaquin River flow reconstructed from tree rings. (Poster presentation). Nineteenth Annual PACLIM Workshop. CALFED, USGS, NOAA, California Dept. of Water Resources, Pacific Grove, CA., March 3.

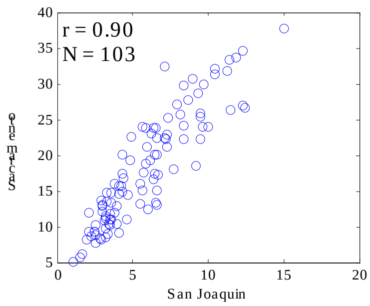
Rivers



1. These are the rivers in question.
2. They broadly represent inflow to the Central Valley from northern California and the Sierra Nevada.

Observed Flows

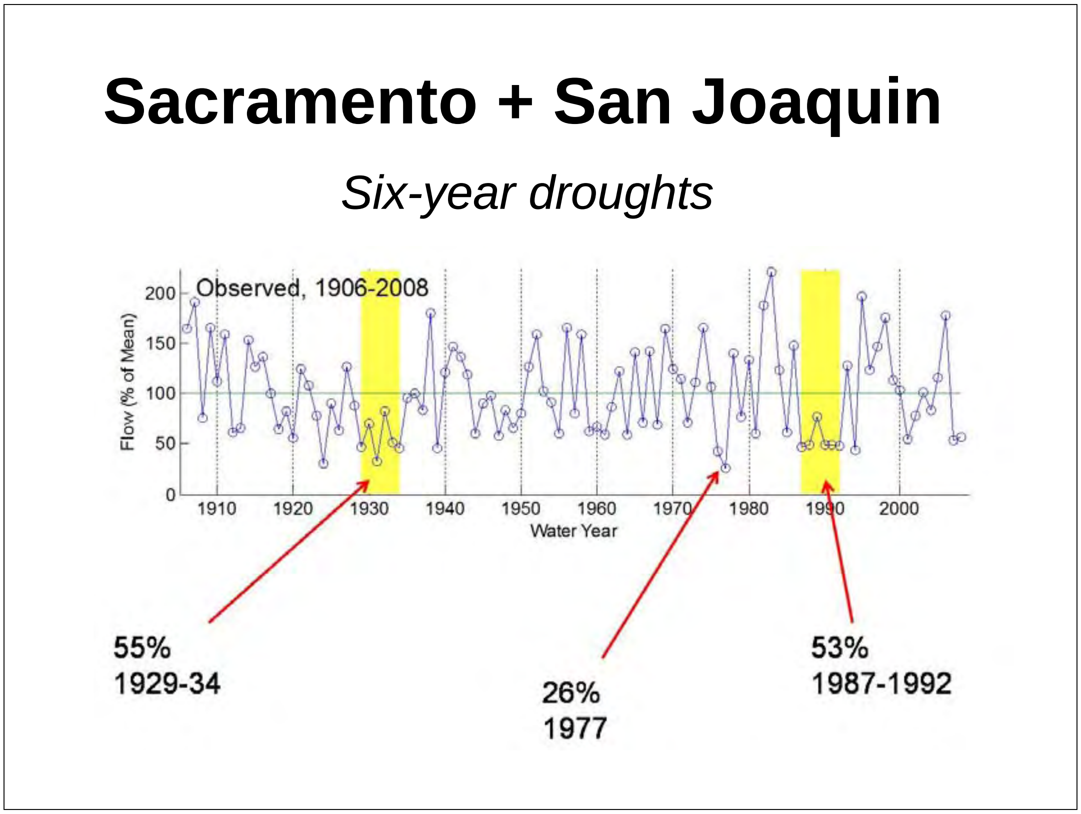




- San Joaquin closely tracks Sacramento
- Driest years largely in common (10 driest marked)
- Tree-ring reconstructions available for both rivers
- Broad view: Sacramento+San Joaquin

1. The observed flow record goes back to near the start of the 20th century.
2. [see slide for other points]

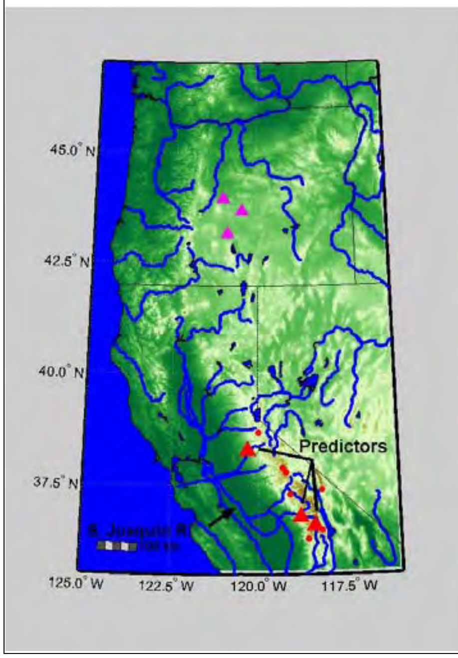
- San Joaquin River Runoff is the sum of Stanislaus River inflow to New Melones Lake, Tuolumne River inflow to New Don Pedro Reservoir, Merced River inflow to Lake McClure, and San Joaquin River inflow to Millerton Lake (in maf).
- Sacramento River Runoff is the sum (in maf) of Sacramento River at Bend Bridge, Feather River inflow to Lake Oroville, Yuba River at Smartville, and American River inflow to Folsom Lake.
- Data from: http://cdec.water.ca.gov/cgi-progs/iodir/WSIHIST
- Horizontal lines at 1906-2008 means: 18.02 MAF and 5.85 MAF



1. The drought histories of the Sacramento and San Joaquin march to the same beat.
2. It is therefore reasonable to use the 2-river sum as a summary variable.
3. The observed record of this sum highlights the single year intensity of drought in 1977, and 6-year droughts in the 1930s and 1980s-90s.

- 1906-2008 mean is 23.8 MAF.
- 1987 and 1992 were both greater than 47% of mean.

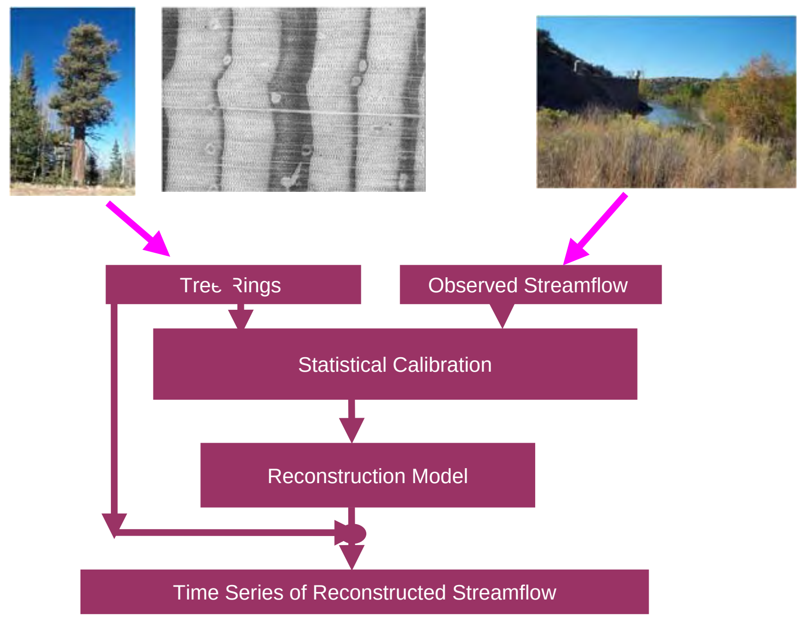
Tree-Ring Network: San Joaquin Reconstruction



- 1000+ year chronologies
- Screened for flow signal
- Applied in regression
- Similar approach for Sacramento River

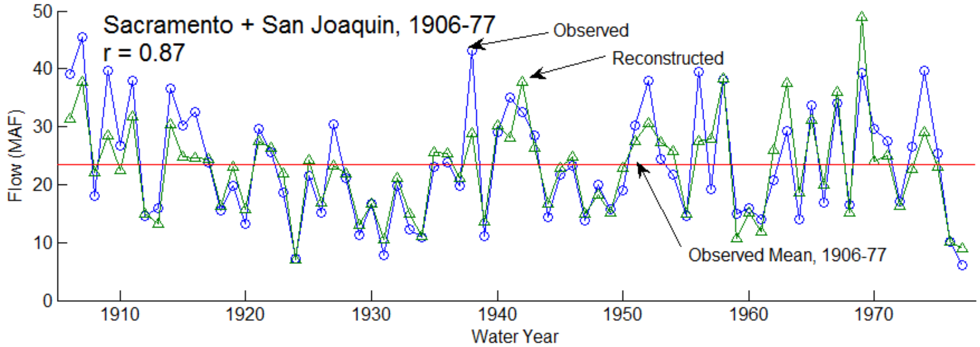
1. For the tree-ring record of the two-year sum, I'll draw on existing reconstruction.
2. Here is the network of tree-ring chronologies used in the San Joaquin reconstruction, done for a PACLIM (Pacific Climate Workshop) presentation in 2002.

Tree-Ring Reconstruction Modeling



1. For the San Joaquin, as well as the Sacramento River reconstruction, the procedure for generating a reconstruction of annual flows is as outlined here.

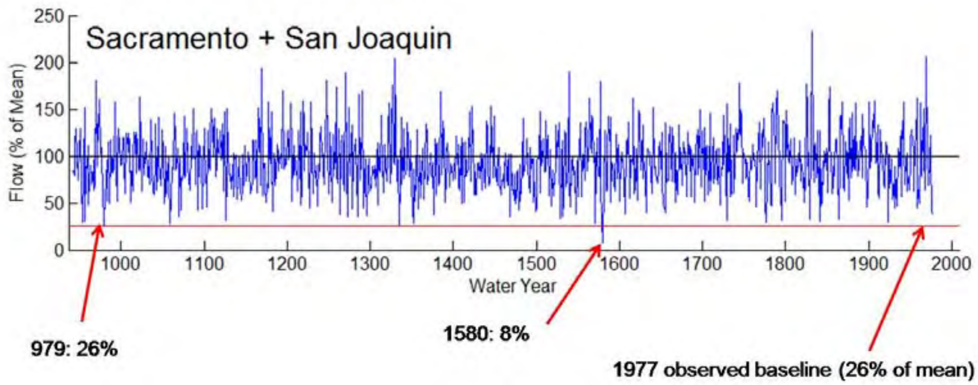
Reconstructed tracks observed



1. These plots show that the sum of the reconstructed flows for the Sacramento and San Joaquin indeed track the observed flows for the period of overlap of flow data and tree rings.
2. [see additional points below]

- Reasonably good tracking at high and low frequencies
- Switch in ranking of 1977 and 1924
- Higher accuracy for low flows than high --- consequence of using log-transformed flows as predicted

Annual Reconstruction, 942-1977



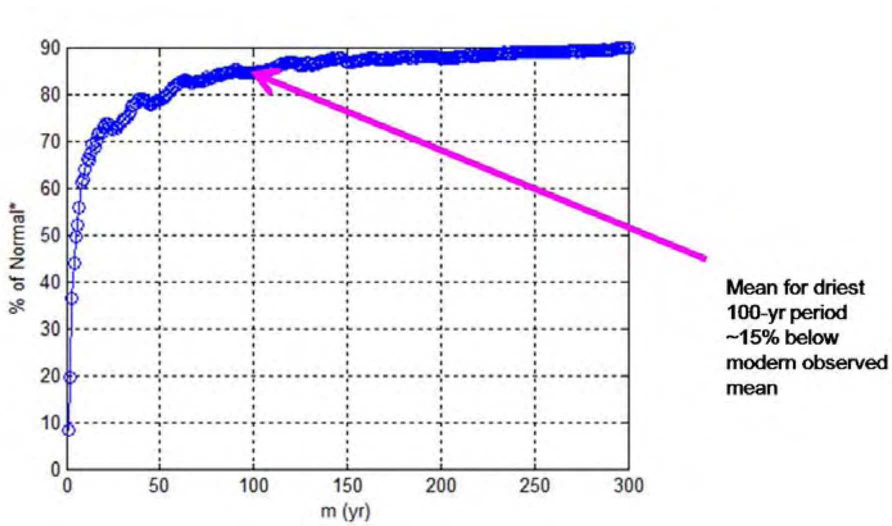
- 20th Century had some very-low-flow years
- 1580: remarkable outlier
- High-flow “voids” – e.g., mid-1100s
- Caveat: reconstruction “conservative”

“Mean” is the 1906-2008 observed mean, 23.9 MAF

1. The two reconstruction jointly cover the years 942-1977.
2. Here is the time series of annual flows, along with threshold drawn at the level of the 1977 flow.
3. [Additional points on figure and below]

- Lowest observed flow: 24% of mean, in 1977
- Only two recon years, 979 and 1580 had lower recon flow than 24% of mean
- Lowest recon flow after 1905: 29.3% of mean in 1924
- Seven recon years drier than 1924 : 979,1059,1335,1352, 1571, 1580, 1777
- Reconstruction “conservative” because not 100 % of variance explained in regression

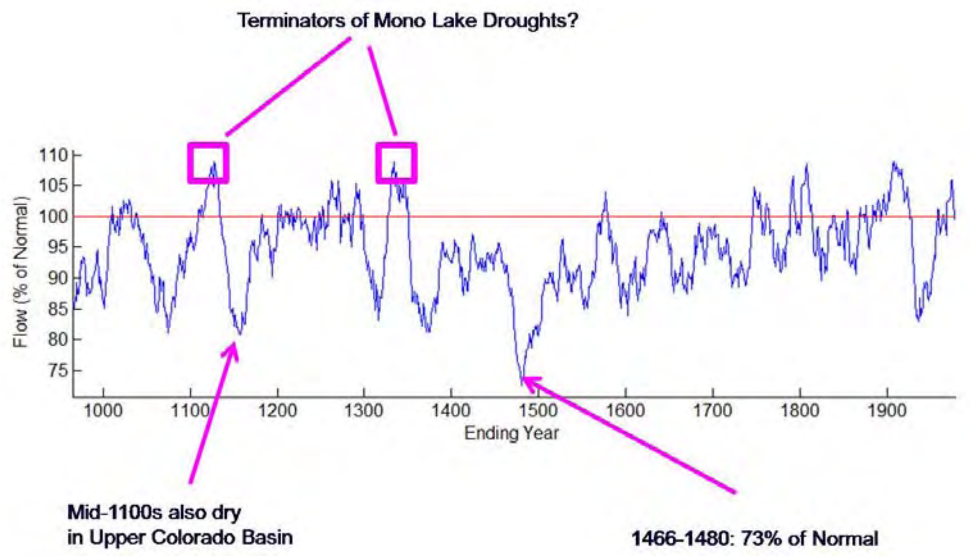
Lowest m-year running means, 942-1977



* “Normal” = 23.9 MAF   (observed mean, 1906-2008)

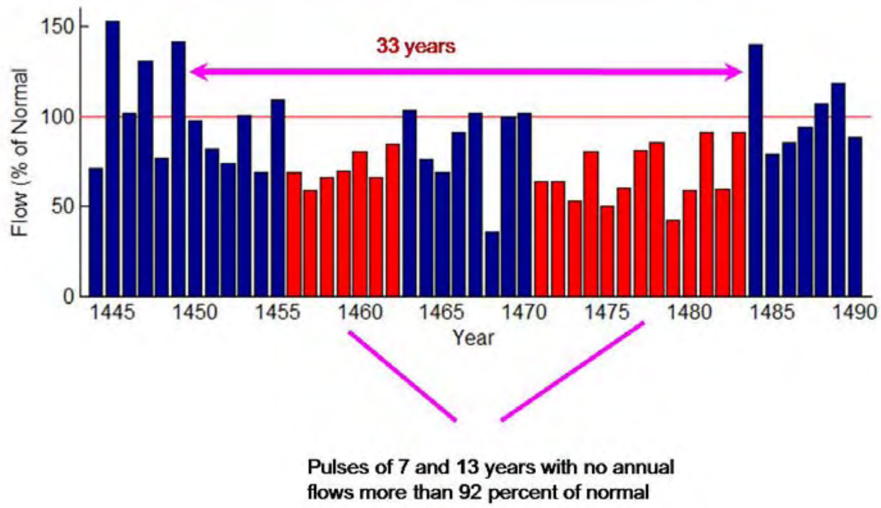
1. The running mean is simple way of summarizing drought severity for different time spans.
2. This plot shows the most extreme droughts – lowest running means – for period lengths 1-300 years.
3. For example, the driest single reconstructed year was 8% of the long-term mean annual flow and the driest 5-year mean was about 50% of the long-term mean.
4. *Note: the long-term reconstructed mean (942-1977) is slightly lower than the observed mean (1906-2008). For this reason, even with a 300-year averaging period the lowest reconstructed running mean is still 10 percent below the observed long-term mean.

25-Year Running Mean



1. Longer running means summarize multi-decadal fluctuations in flow.
2. This plots summarizes reconstructed flow for overlapping 25-year period.
3. The driest period by this measure was in the mid-late 1400s.
4. Persistent dry conditions in the mid-1100s coincide with one of the lowest-flow periods reconstructed for the Colorado River (GRL, Meko et al. 2007).
5. The wet periods peaking in the early 1100s and and mid 1300s are consistent with ending dates of droughts inferred from low stands in Mono Lake.
6. But perhaps the Mono Lake record has no recorded evidence for a drought in the mid-1400s (the absence of recording stumps, etc., does not necessarily mean a drought did not occur then).

Close-up of 1400s drought



1. The 1400s drought in zoomed view shows up as an extended period of 33 years without any flow more than a few percent above the long-term mean.
2. A signature of the drought was a double pulse of low-flow years (see figure).
3. The second pulse looks considerably more severe than the 1930s drought; that drought had a 10-year period with flows in all years below the mean or just above the mean.
4. The two pulses in rapid succession without any very wet intervening years would be an event without analog in gaged-flow period as far as combined duration and severity of drought.

1. The drought chronology of the Central Valley prior to about A.D. 1500 is still uncertain because of the scarcity of high-quality moisture sensitive tree-ring series from northern California.
2. Improvement await better data coverage, and innovations in reconstruction modeling.