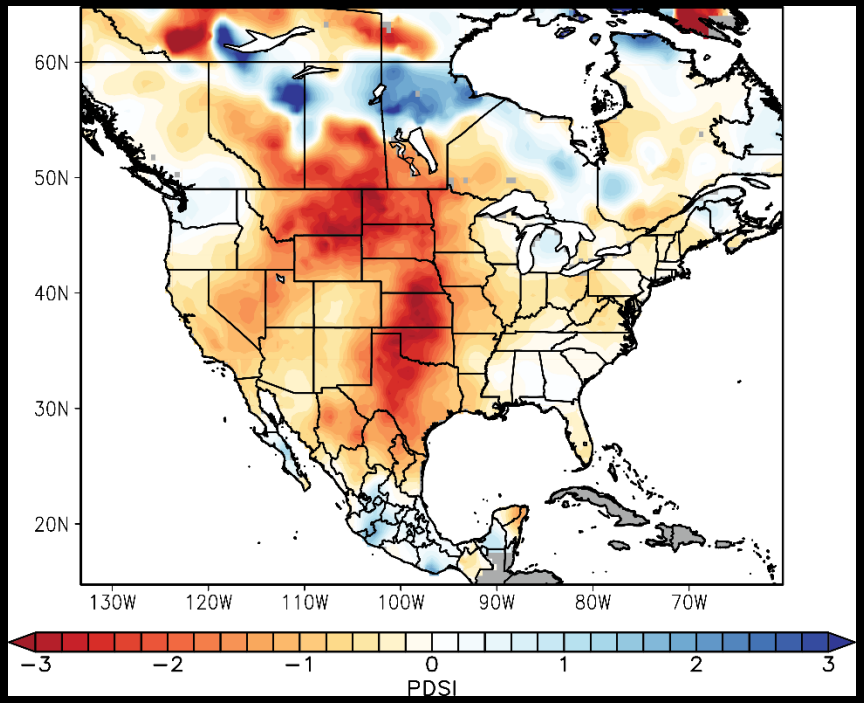
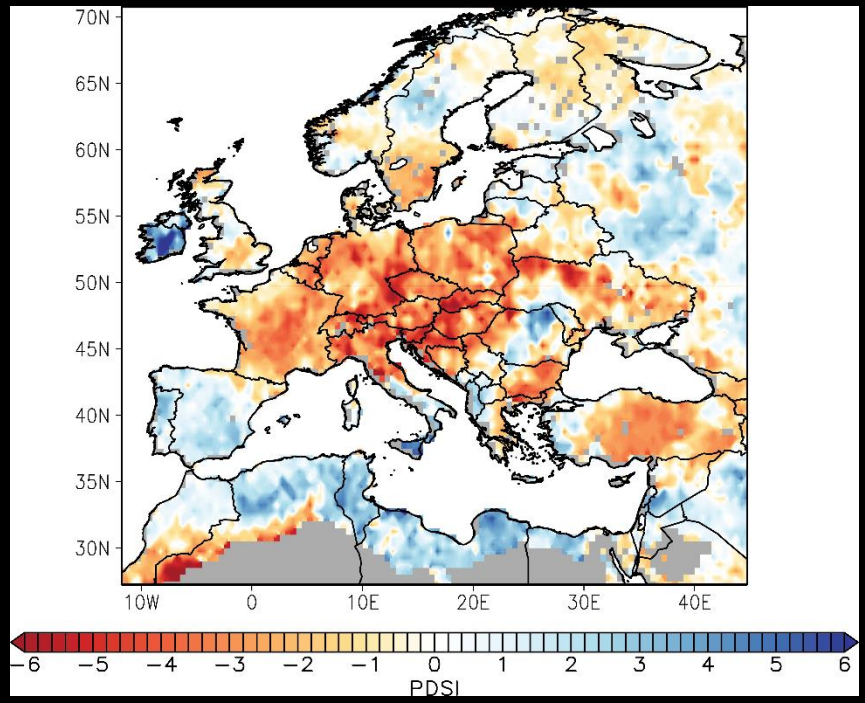
Tree-Ring Reconstructed Drought Atlases: How did we get here?

Dr. Dorian J. Burnette, Dept. of Earth Sciences, University of Memphis

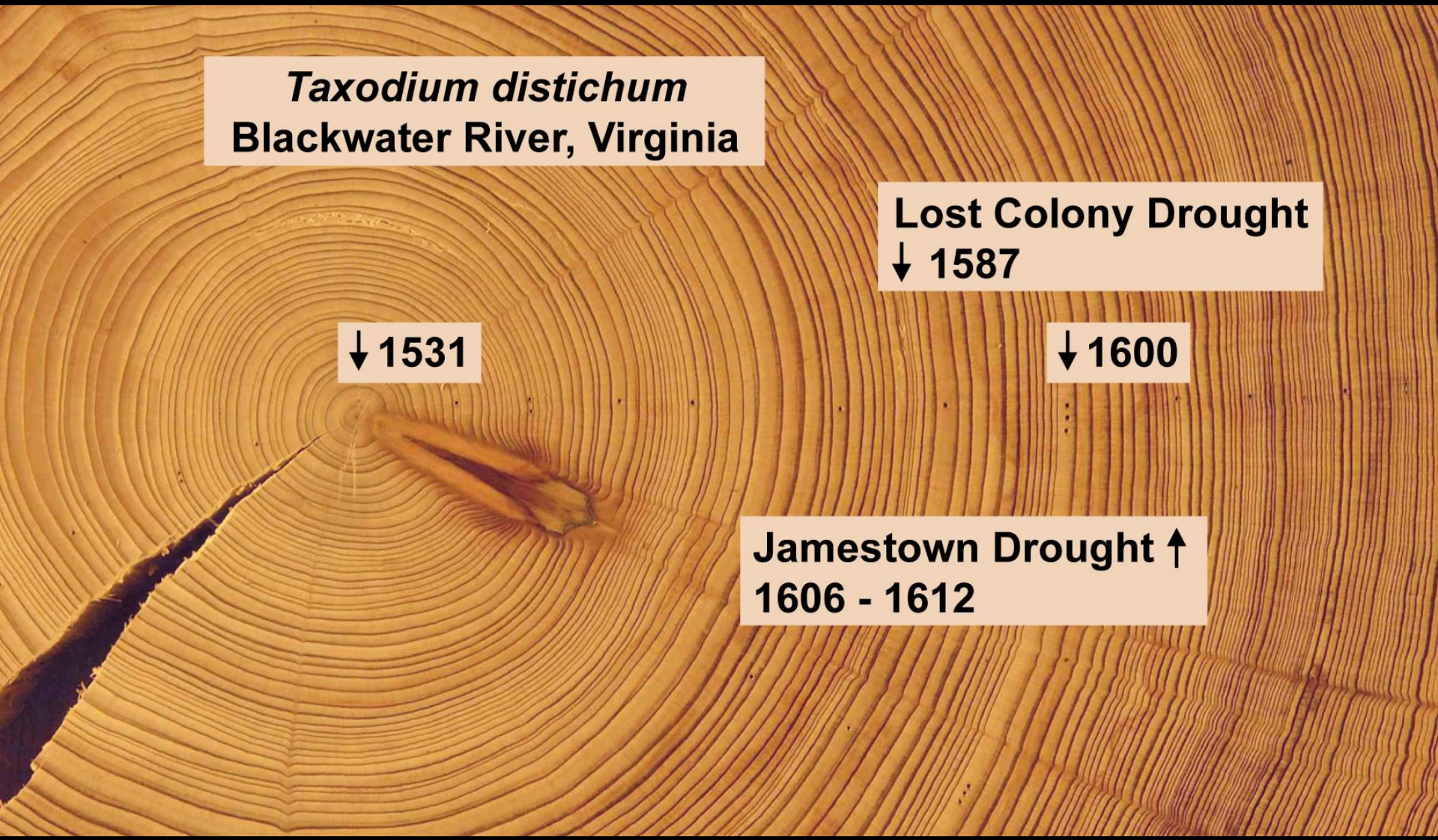


Mid-19th Century Drought 1856-1865
North American Drought Atlas



1540 Drought
Old World Drought Atlas

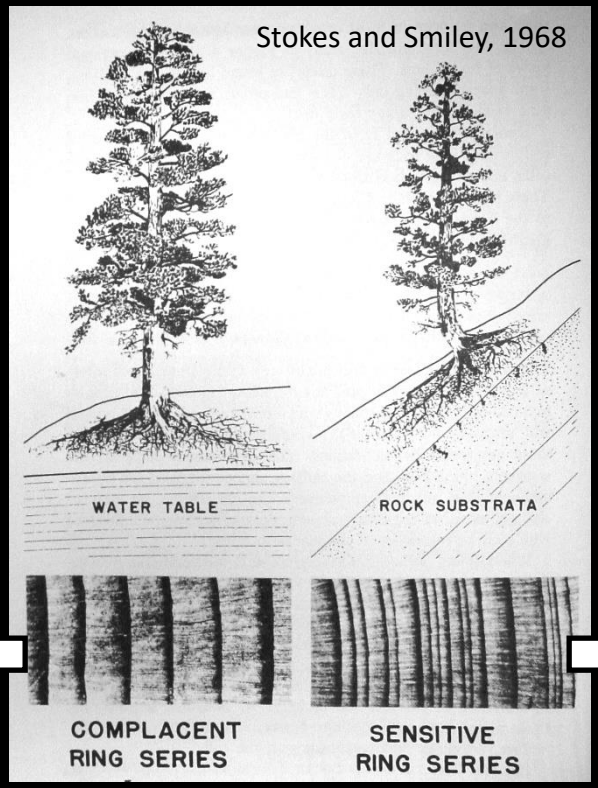
Dendrochronology

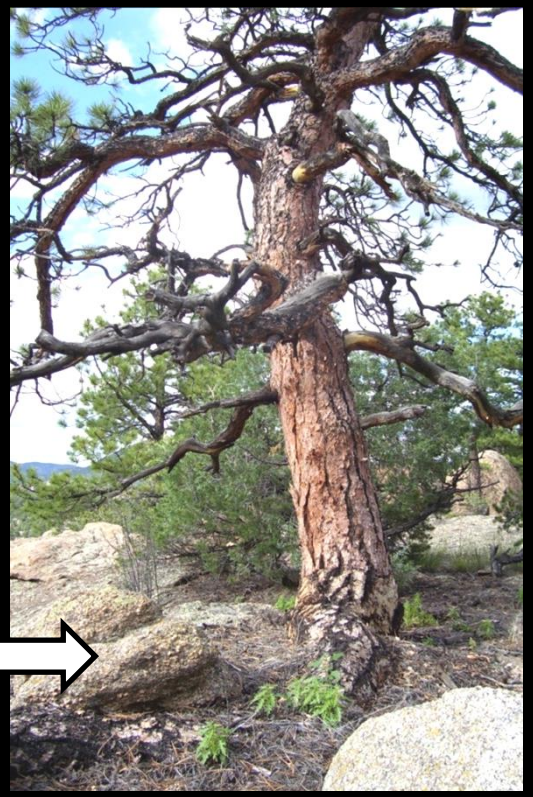


Tree-Ring Dating = the most accurate and precise dating method in geochronology

Principle of Site Selection

Southern beech
(Nothofagus sp.)
Chile

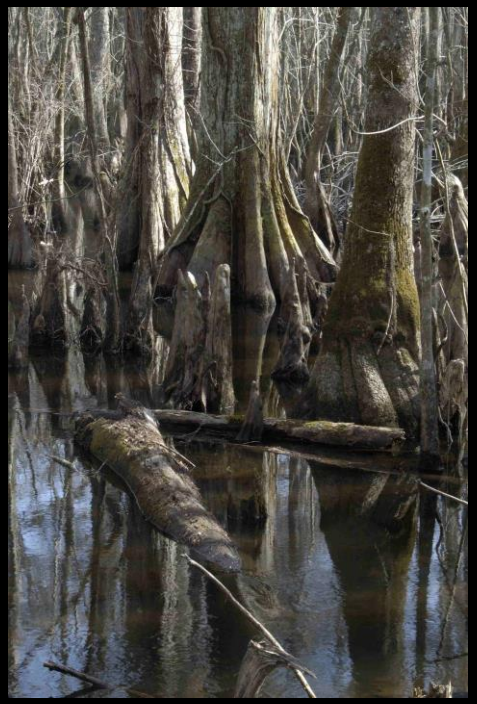


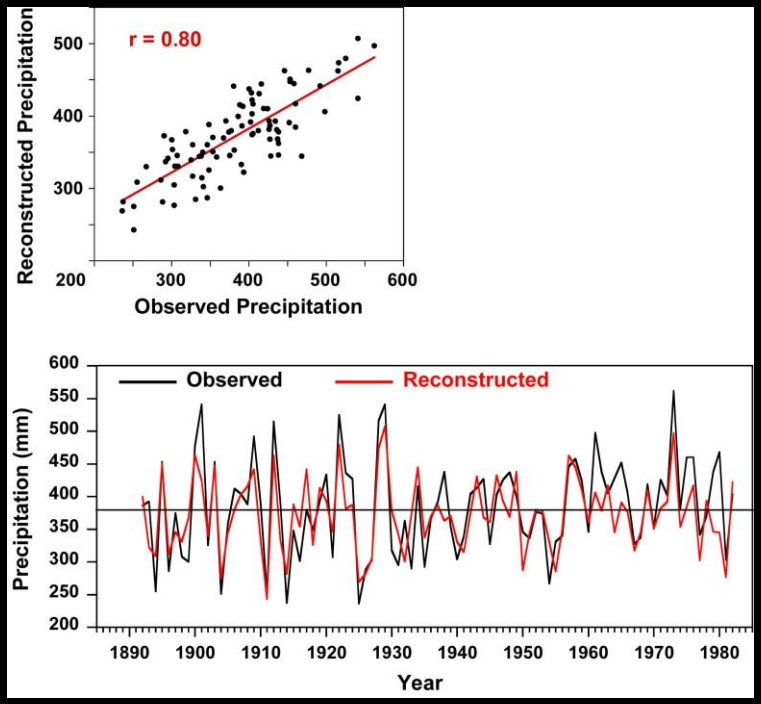


Ponderosa pine
(Pinus ponderosae)
Colorado

- Require trees sensitive to variations in environmental conditions
- Size not necessarily equal to age
- Longevity under adversity
- Need non-commercial sites

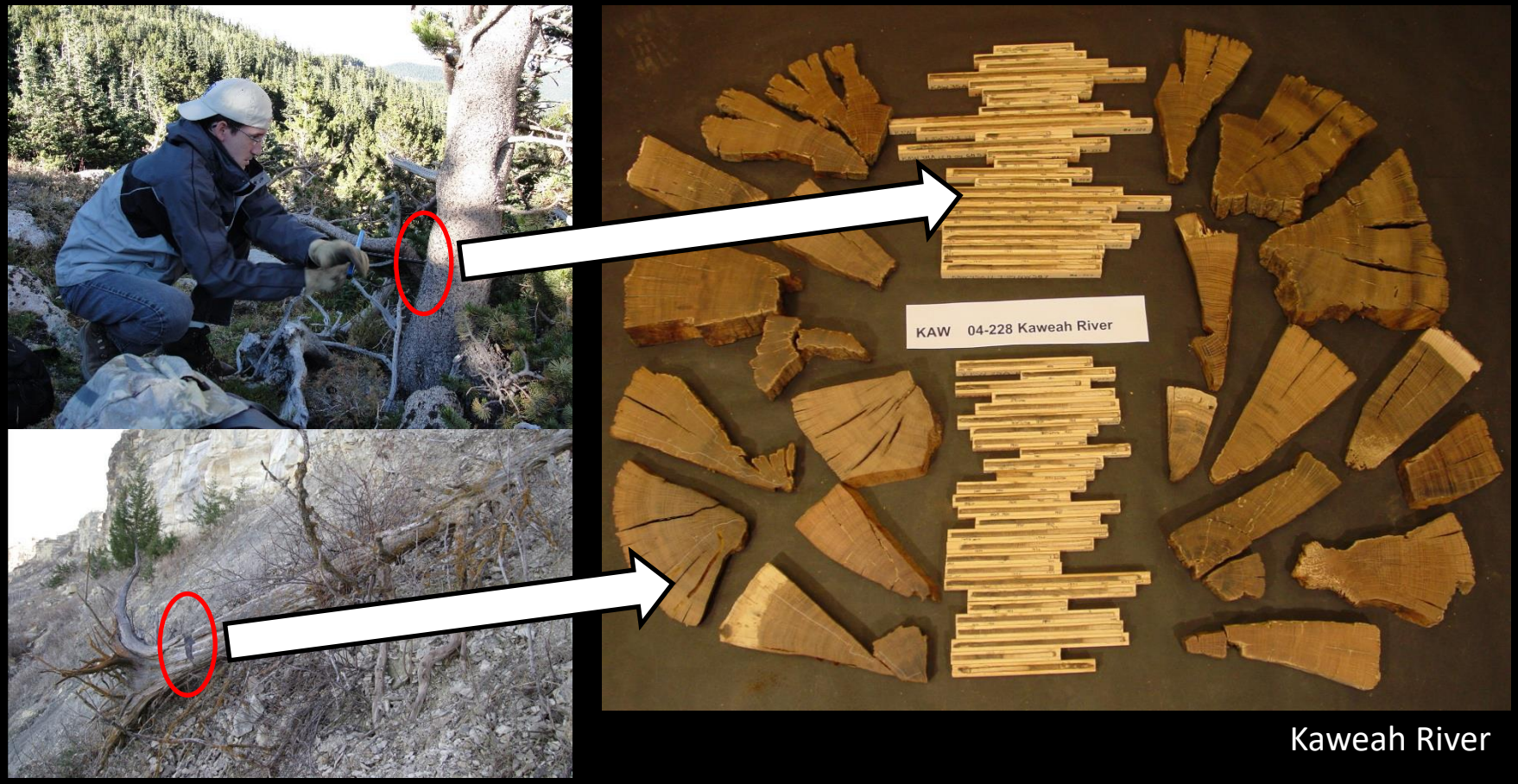
Principle of Site Selection





- Dependent on the species:
  - Baldcypress growth is directly correlated with rainfall, in spite of flooded habitat
  - Dissolved oxygen gradient, stratification of root system, low flows during drought, high evapotranspiration demand, negative correlation between temperature and dissolved oxygen

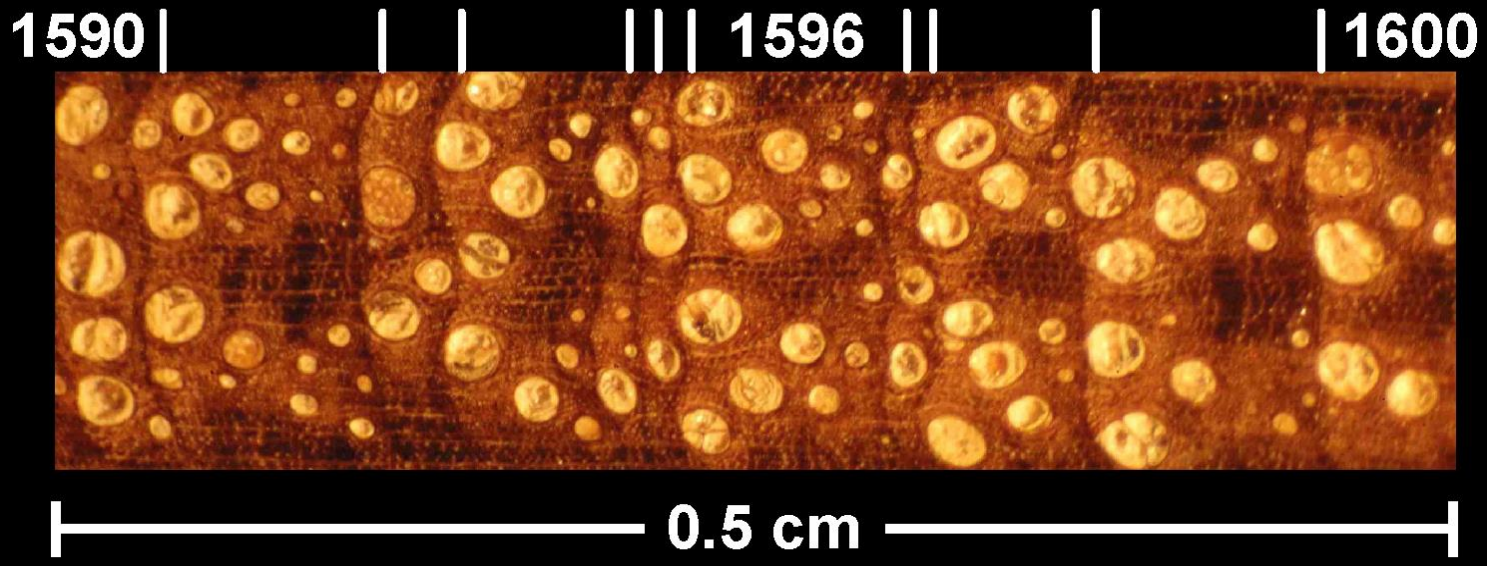
Tree-Ring Samples



Kaweah River

- Massive replication with 50-100 trees sampled per site = dendrochronology

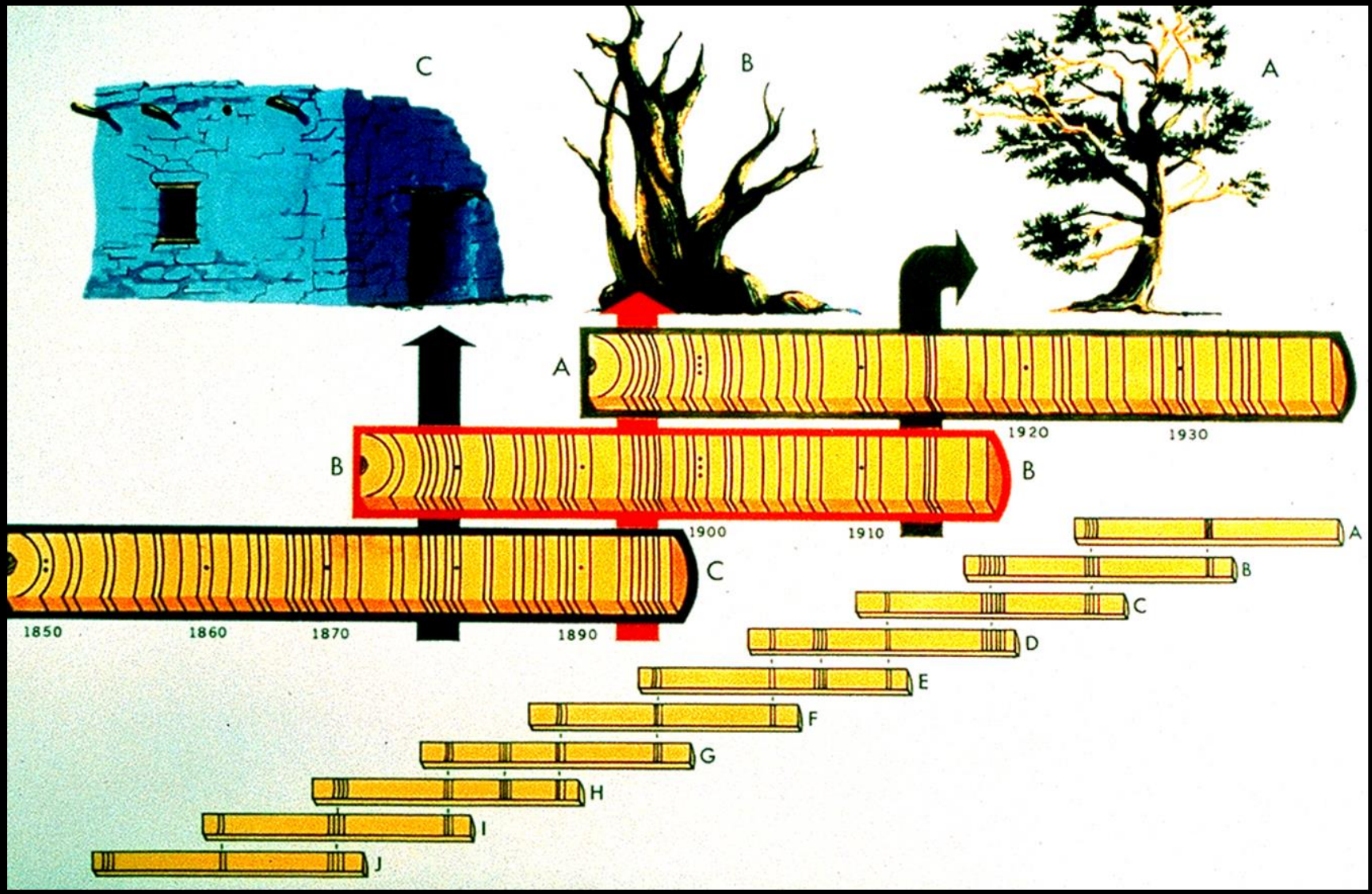
Tree-Ring Chronology Development



Annual Growth Rings, Blue Oak

- Dating completed to the precise calendar year

Tree-Ring Chronology Development



The ‘Bridge Method’ of chronology extension into prehistory

The Skeleton Plot

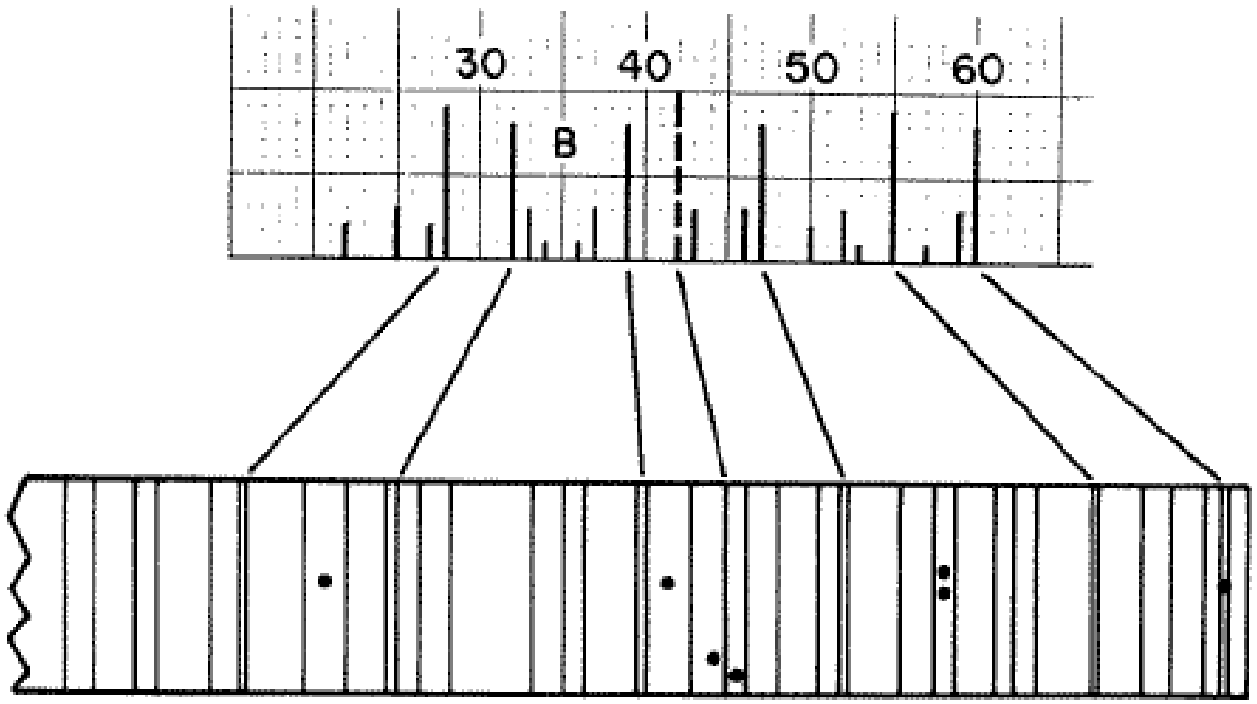


FIG. 7. Construction of a skeleton plot from an idealized tree-ring sequence. Ring widths are represented on the plot by vertical lines in an inverse proportion; that is, tall lines represent narrow rings. An exceptionally wide ring is designated by a "B" (big), and the location of a missing ring, marked on the specimen by offset pinholes, is identified on the plot by a full two-centimeter line in red (dashed). Horizontal scale is 1 year per 2 mm.

From Ferguson 1970, Concepts and Techniques of Dendrochronology

COFECHA

```
                    P R O G R A M     C O F E C H A

                    Version 6.06P 10:41  Tue 29 Nov 2005
«»«»«»«»«»«»«»«»«»«»«»«»«»«»«»«»«»«»«»«»«»«»«»«»«»«»«»«»«»«»«»«»«»«»«»«»«»«»

Program COFECHA does data quality control on a set of tree-ring measurements,
verifying crossdating among measurement series and indicating possible dating
or measurement problems.  It identifies portions of tree-ring series that may
have dating errors or important errors in measurement.  You may also check
crossdating among chronologies.

Before problems are identified each time series is transformed to enhance
characteristics related to crossdating.  Low-frequency variance is removed
by cubic smoothing spline.  Autoregressive modeling removes persistence.
To weigh proportional differences equally the series is log-transformed.
Each transformed series is then tested against the master dating series
segment by segment, and successive segments are lagged with a 50% overlap.

Maximum time span  4096 years                    For more information type:  ?

Identify job (up to 5 characters) => B27

CROSSDATED TREE-RING SERIES
 ... Name of EXISTING INPUT file => B27.raw

___First  8 lines___B27.raw
Blue Oak Site 27, (Rock Springs Ranch, San Benito County, CA, USA. B27 QUDG +3
1067M RW UAFACC#=04-201 Coll: Stahle, Griffin 03/23/2004 1379-2003
B2701A  1836    996  1334  2131  1496
B2701A  1840  1697   263  1807   267   463   584   559  1347  1301  1223
B2701A  1850  1673   708  1936  1715   963  1138   320   434   265   562
B2701A  1860  1038   944  3086   732   157   618   605  1671  4566  1762
B2701A  1870  1013  1024  2146  1332  1458  1262  2577   387  2433   279
B2701A  1880  1250   826  1200   809  3451  1363  2835  1222  1302  1236
....:....1....:....2....:....3....:....4....:....5....:....6....:....7....:....
Format is Measurements, correct?  <Y>/N =>
Checking time span
Time series span  1379  2003   625 years   21 series, mean length   230.19 yrs
No time interval is covered by all series

UNDATED TREE-RING SERIES
 ... Name of EXISTING INPUT file =>

TITLE OF THIS RUN => Rock Springs Ranch, CA Blue Oak, Teaching Collection

                                C O F E C H A
Select number or first letter to modify:         Current values

1  Rigidity of SPLINE for filtering                  32
2  SEGMENT length to examine                         50 lagged  25
3  AUTOREGRESSIVE MODEL                               A
4  TRANSFORM series to logarithms                     Y
5  CORRELATION critical level                      .3281  Type P
6  MASTER dating series, save                         N
7  LIST ring measurements                             N
8  Parts of output to print                     1234567
9  Omit absent rings in master series & segment corr  Y
F  First-difference transform of data                 N

Initial or number of option or <CR> to proceed =>
```

- Spanish for crossdate
- Segmented correlation analysis program
  - Holmes (1983, *Tree-Ring Bulletin*)
  - Grissino-Mayer (2001, *Tree-Ring Research*)

COFECHA

PART 5: CORRELATION OF SERIES BY SEGMENTS: Rock Springs Ranch Blue Oak Teaching 10:36 Tue 29 Nov 2005 Page 5

Correlations of 50-year dated segments, lagged 25 years
Flags: A = correlation under .3281 but highest as dated; B = correlation higher at other than dated position

Seq	Series	Time_span	1375 1424	1400 1449	1425 1474	1450 1499	1475 1524	1500 1549	1525 1574	1550 1599	1575 1624	1600 1649	1625 1674	1650 1699	1675 1724	1700 1749	1725 1774	1750 1799	1775 1824	1800 1849	1825 1874	1850 1899
1	B2701A	1836 2003																			.93	.95
2	B2702A	1826 2003																			.88	.91
3	B2707A	1813 2003																		.80	.85	.86
4	B2722A	1676 1986													.90	.89	.86	.87	.87	.88	.90	.94
5	B2729A	1838 2003																			.89	.91
6	B2735A	1790 2003																	.85	.82	.87	.91
7	B2740A	1874 2000																				.90
8	B2743A	1629 1920											.88	.90	.91	.91	.88	.91	.84	.83	.90	.91
9	B2744A	1698 1900													.86	.85	.83	.89	.93	.93	.93	.90
10	B2747A	1670 1906												.86	.86	.85	.82	.84	.90	.89	.78	.77
11	B2748B	1619 1890										.90	.91	.91	.85	.82	.83	.83	.87	.84	.85	.82
12	B2754A	1855 2003																				.75
13	B2761A	1746 1980															.86	.87	.90	.92	.91	.92
14	B2765A	1511 1696						.76	.65	.66	.83	.81	.87	.85								
15	B2767A	1640 1890											.57	.83	.92	.87	.87	.89	.71	.68	.86	.81
16	B2770B	1578 1860									.75	.82	.91	.89	.89	.91	.84	.84	.83	.82	.81	
17	B2773B	1524 1839						.70	.69	.67	.80	.79	.86	.89	.85	.78	.82	.89	.86	.84		
18	B2776A	1379 1525	.71	.73	.75	.80	.81	.82														
19	B2777A	1618 1870										.91	.91	.87	.84	.81	.68	.73	.86	.85	.88	
20	B2779A	1471 1677				.77	.82	.83	.69	.65	.76	.75	.82	.83								
21	B2780B	1397 1844	.71	.73	.73	.82	.87	.88	.75	.76	.83	.84	.91	.89	.87	.78	.56	.60	.87	.90		
Av segment correlation			.71	.73	.74	.80	.83	.80	.70	.69	.79	.83	.85	.87	.87	.85	.80	.83	.86	.85	.87	.88

PART 5: CORRELATION OF SERIES BY SEGMENTS: Rock Springs Ranch Blue Oak Teaching 10:36 Tue 29 Nov 2005 Page 6

Correlations of 50-year dated segments, lagged 25 years
Flags: A = correlation under .3281 but highest as dated; B = correlation higher at other than dated position

Seq	Series	Time_span	1875 1924	1900 1949	1925 1974	1950 1999	1975 2024
1	B2701A	1836 2003	.95	.93	.94	.96	.97
2	B2702A	1826 2003	.89	.87	.93	.93	.92
3	B2707A	1813 2003	.87	.87	.87	.90	.90
4	B2722A	1676 1986	.89	.79	.83	.80	
5	B2729A	1838 2003	.78	.76	.90	.89	.86
6	B2735A	1790 2003	.91	.88	.91	.93	.92
7	B2740A	1874 2000	.91	.87	.84	.88	.88
8	B2743A	1629 1920	.89				
9	B2744A	1698 1900	.90				
10	B2747A	1670 1906	.77				
12	B2754A	1855 2003	.81	.74	.83	.86	.85
13	B2761A	1746 1980	.92	.84	.82	.82	
Av segment correlation			.87	.84	.87	.89	.90

COFECHA

PART 5: CORRELATION OF SERIES BY SEGMENTS: 15:37 Tue 29 Nov 2005 Page 5

Correlations of 50-year dated segments, lagged 25 years
Flags: A = correlation under .3281 but highest as dated; B = correlation higher at other than dated position

Seq	Series	Time_span	1375 1424	1400 1449	1425 1474	1450 1499	1475 1524	1500 1549	1525 1574	1550 1599	1575 1624	1600 1649	1625 1674	1650 1699	1675 1724	1700 1749	1725 1774	1750 1799	1775 1824	1800 1849	1825 1874	1850 1899
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4	B2722A	1676 1986													.89	.88	.85	.86	.88	.88	.89	.93
5	B2729A	1838 2003																			.90	.91
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7	B2740A	1874 2000																				.90
8	B2743A	1629 1920											.86	.87	.89	.91	.87	.89	.83	.83	.89	.91
9	B2744A	1698 1900													.85	.84	.84	.89	.92	.91	.91	.89
10	B2747A	1670 1906												.84	.84	.86	.82	.83	.90	.88	.77	.76
11	B2748B	1619 1890										.89	.90	.91	.84	.82	.82	.83	.86	.83	.83	.81
12	B2754A	1855 2003																				.77
13	B2761A	1746 1980															.86	.87	.90	.91	.90	.91
14	B2765A	1511 1695						.76	.64	.13B	-.04B	-.07B	-.04B	-.13B								
15	B2767A	1640 1891											.61	.61	.65	.73	.64	.28A	.09B	.07B	.14B	-.05B
16	B2770B	1578 1860									.64	.78	.89	.87	.88	.91	.84	.83	.84	.83	.81	
17	B2773B	1524 1839						.70	.69	.57	.70	.73	.84	.89	.86	.78	.81	.88	.86	.84		
18	B2776A	1379 1525	.71	.73	.75	.80	.81	.82														
19	B2777A	1618 1870										.87	.87	.85	.84	.80	.66	.71	.84	.85	.89	
20	B2779A	1471 1677				.77	.82	.83	.69	.62	.69	.69	.81	.83								
21	B2780B	1397 1844	.71	.73	.73	.82	.87	.88	.75	.68	.75	.81	.90	.88	.85	.78	.57	.58	.85	.89		
Av segment correlation			.71	.73	.74	.80	.83	.80	.69	.50	.55	.67	.74	.74	.84	.83	.78	.77	.80	.80	.82	.81

PART 5: CORRELATION OF SERIES BY SEGMENTS: 15:37 Tue 29 Nov 2005 Page 6

Correlations of 50-year dated segments, lagged 25 years
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Seq	Series	Time_span	1875 1924	1900 1949	1925 1974	1950 1999	1975 2024
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2	B2702A	1826 2003	.88	.87	.93	.93	.92
3	B2707A	1813 2003	.87	.87	.87	.90	.90
4	B2722A	1676 1986	.89	.79	.83	.80	
5	B2729A	1838 2003	.78	.76	.90	.89	.86
6	B2735A	1790 2003	.91	.88	.91	.93	.92
7	B2740A	1874 2000	.90	.87	.84	.88	.88
8	B2743A	1629 1920	.90				
9	B2744A	1698 1900	.89				
10	B2747A	1670 1906	.77				
12	B2754A	1855 2003	.81	.74	.83	.86	.85
13	B2761A	1746 1980	.92	.84	.82	.82	
Av segment correlation			.87	.84	.87	.89	.90

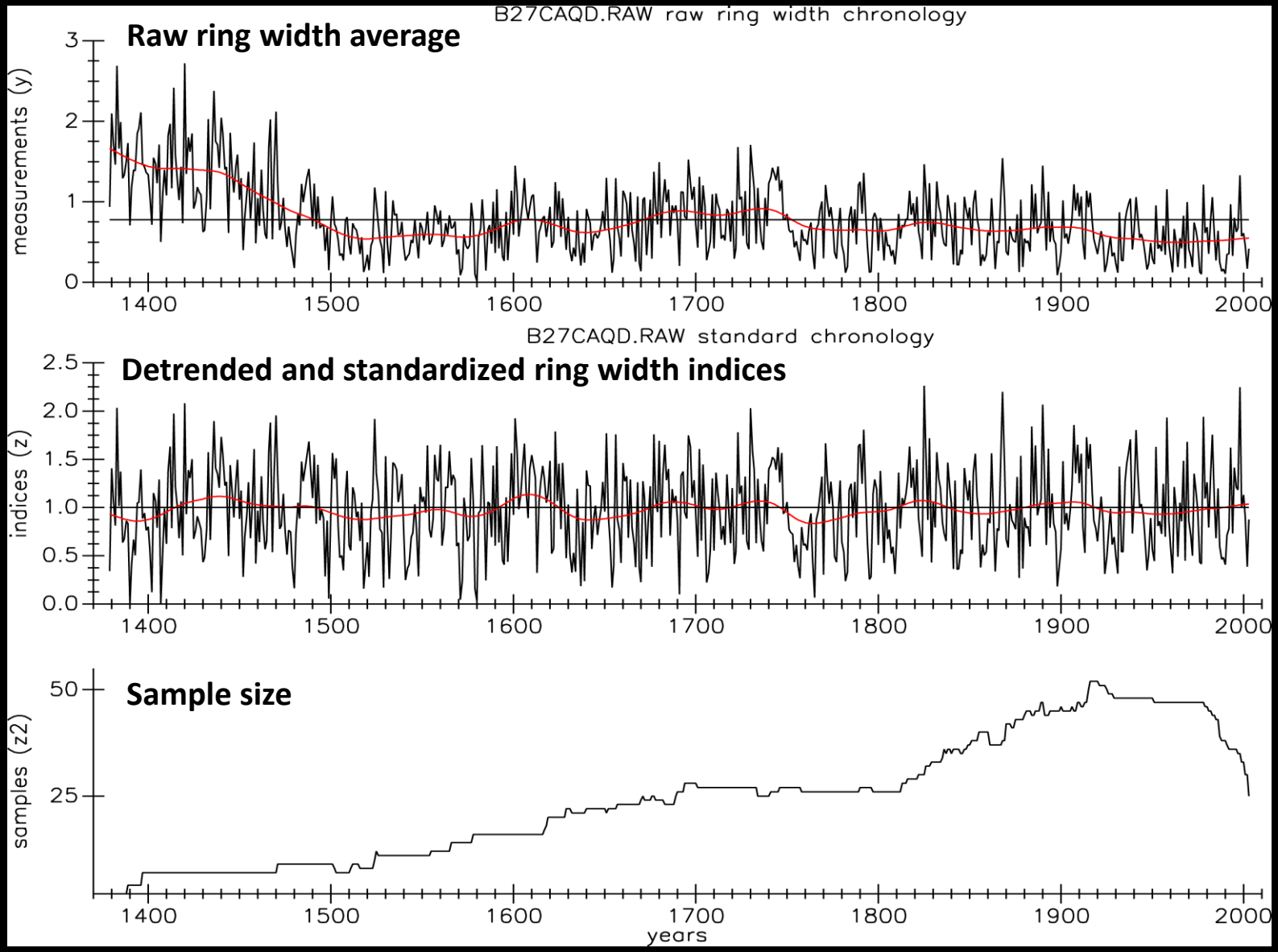
COFECHA

```
B2765A    1511 to  1695     185 years                                                                                                    Series  14

[A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
   ---------  ----  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
   1550 1599    1   .04  .20 -.10 -.05 -.18 -.11  .27 -.21  .02  .14  .13| .32*-.39 -.05  .05 -.06  .25 -.04  .09  .12 -.10
   1575 1624    1  -.19 -.03 -.06 -.02 -.11  .03  .27 -.22 -.10  .03 -.04| .77*-.30  .06  .02 -.05  .16 -.27 -.09  .09 -.11
   1600 1649    1  -.15 -.04 -.08  .03 -.09 -.09  .12 -.06 -.11  .01 -.07| .82*-.04  .10  .00 -.09  .00 -.17  .01  .06 -.08
   1625 1674    1   .15  .08 -.30 -.06  .01 -.19 -.08  .08 -.02 -.02 -.04| .87* .05 -.13  .04 -.05 -.15 -.13 -.01 -.14  .08
   1646 1695    1   .07 -.14 -.13 -.02 -.13 -.08 -.12 -.04  .09 -.04 -.13| .87* .10 -.16  .08  .04 -.01 -.22 -.15 -.25  .04

[B] Entire series, effect on correlation (  .124) is:
      Lower   1691> -.022   1612< -.022   1639> -.017   1676> -.015   1622> -.011   1668< -.011  Higher   1579  .019   1532  .016
    1550 to 1599 segment:
      Lower   1595> -.048   1565< -.040   1591< -.039   1599< -.035   1596< -.026   1588> -.024  Higher   1579  .091   1594  .058
    1575 to 1624 segment:
      Lower   1612< -.035   1622> -.029   1595> -.027   1591< -.024   1599< -.023   1596< -.017  Higher   1579  .073   1613  .051
    1600 to 1649 segment:
      Lower   1639> -.051   1622> -.033   1612< -.024   1635< -.020   1637> -.014   1634> -.013  Higher   1613  .069   1621  .028
    1625 to 1674 segment:
      Lower   1639> -.064   1668< -.040   1667> -.039   1655> -.035   1635< -.025   1670> -.020  Higher   1654  .057   1669  .036
    1646 to 1695 segment:
      Lower   1676> -.039   1691> -.034   1668< -.031   1667> -.028   1655> -.025   1680< -.022  Higher   1654  .057   1669  .036

[C] Year-to-year changes diverging by over 4.0 std deviations:
      1612 1613   6.2 SD    1690 1691   4.6 SD

[E] Outliers     22   3.0 SD above or -4.5 SD below mean for year
      1565 -4.7 SD;    1580 +4.3 SD;    1588 +3.8 SD;    1590 +3.2 SD;    1595 +5.0 SD;    1597 +3.1 SD;    1603 +3.0 SD;
      1612-10.7 SD;    1613 +5.3 SD;    1622 +5.6 SD;    1626 +3.1 SD;    1634 +3.1 SD;    1637 +3.8 SD;    1639 +6.0 SD;
      1655 +5.1 SD;    1667 +5.1 SD;    1668 -5.0 SD;    1670 +4.1 SD;    1676 +5.5 SD;    1679 +3.3 SD;    1691 +8.8 SD;
      1695 +3.1 SD
```

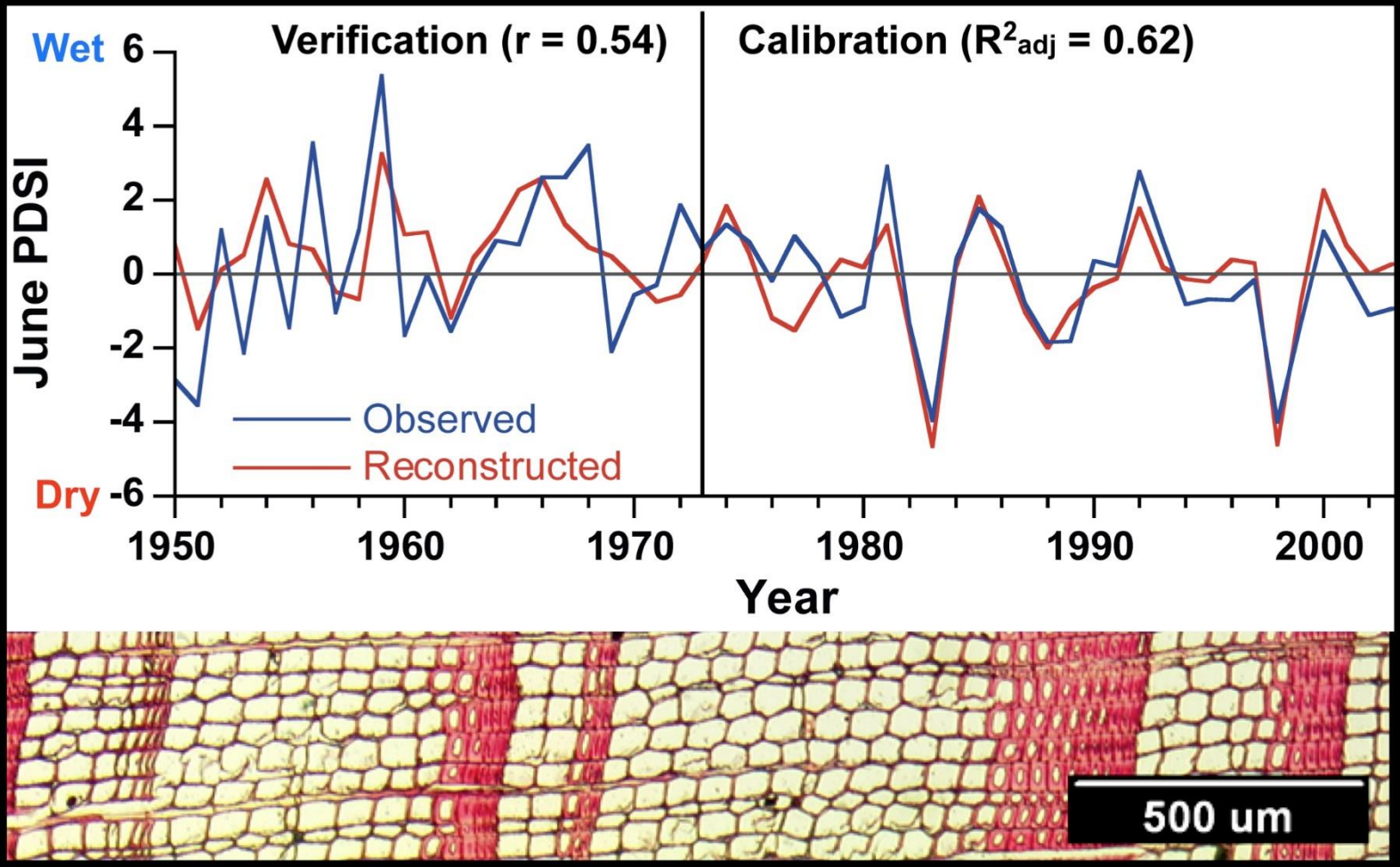
ARSTAN

- Autoregressive Modeling Standardization (ARSTAN)
  - Cook (1985, Ph.D. Dissertation, University of Arizona)
- Used to develop tree-ring chronologies

ARSTAN


B27CAQD.RAW raw ring width chronology
Raw ring width average
measurements (y)
3
2
1
0
1400
1500
1600
1700
1800
1900
2000
B27CAQD.RAW standard chronology
Detrended and standardized ring width indices
indices (z)
2.5
2.0
1.5
1.0
0.5
0.0
1400
1500
1600
1700
1800
1900
2000
Sample size
samples (z2)
50
25
1400
1500
1600
1700
1800
1900
2000
years

Mesoamerican Megadroughts

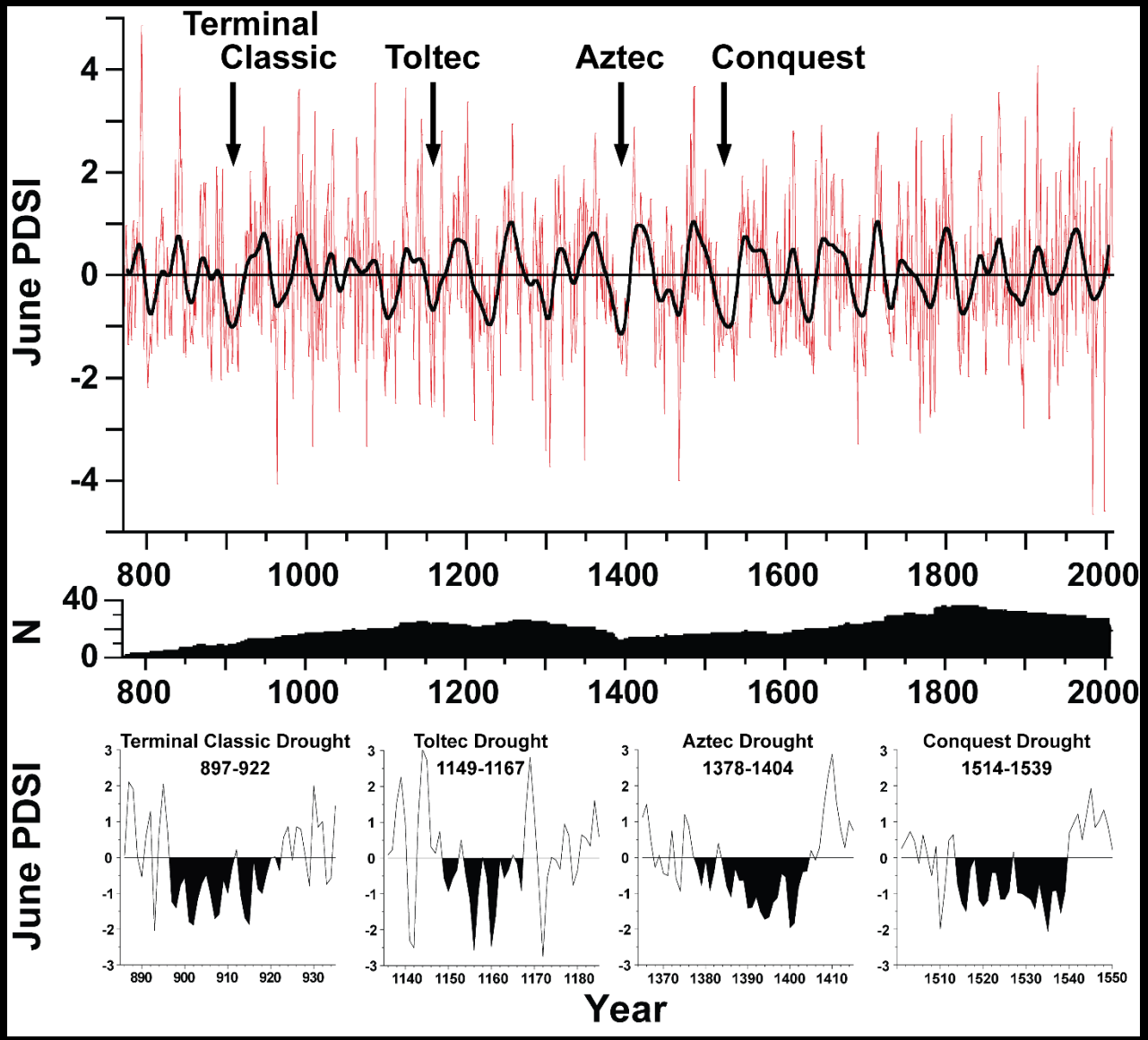


Stahle et al. 2011, *Geophysical Research Letters*

Taxodium, RD Griffin

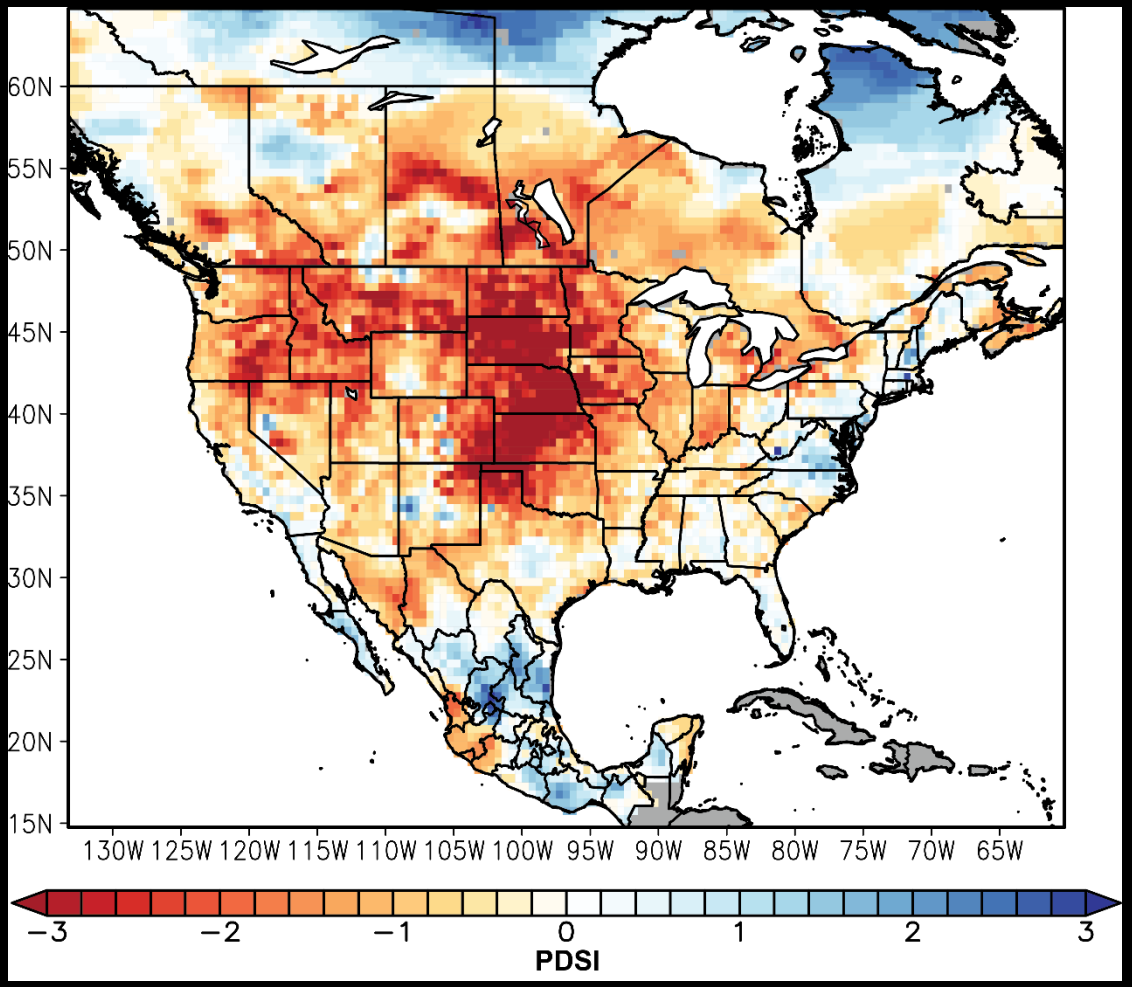
Basalt & ancient Montezuma baldypress, Barranca de Amealco, Queretaro
90 km from the Temple of the Sun, 60 km from Tula
New chronology: AD 771 - 2008

Mesoamerican Megadroughts



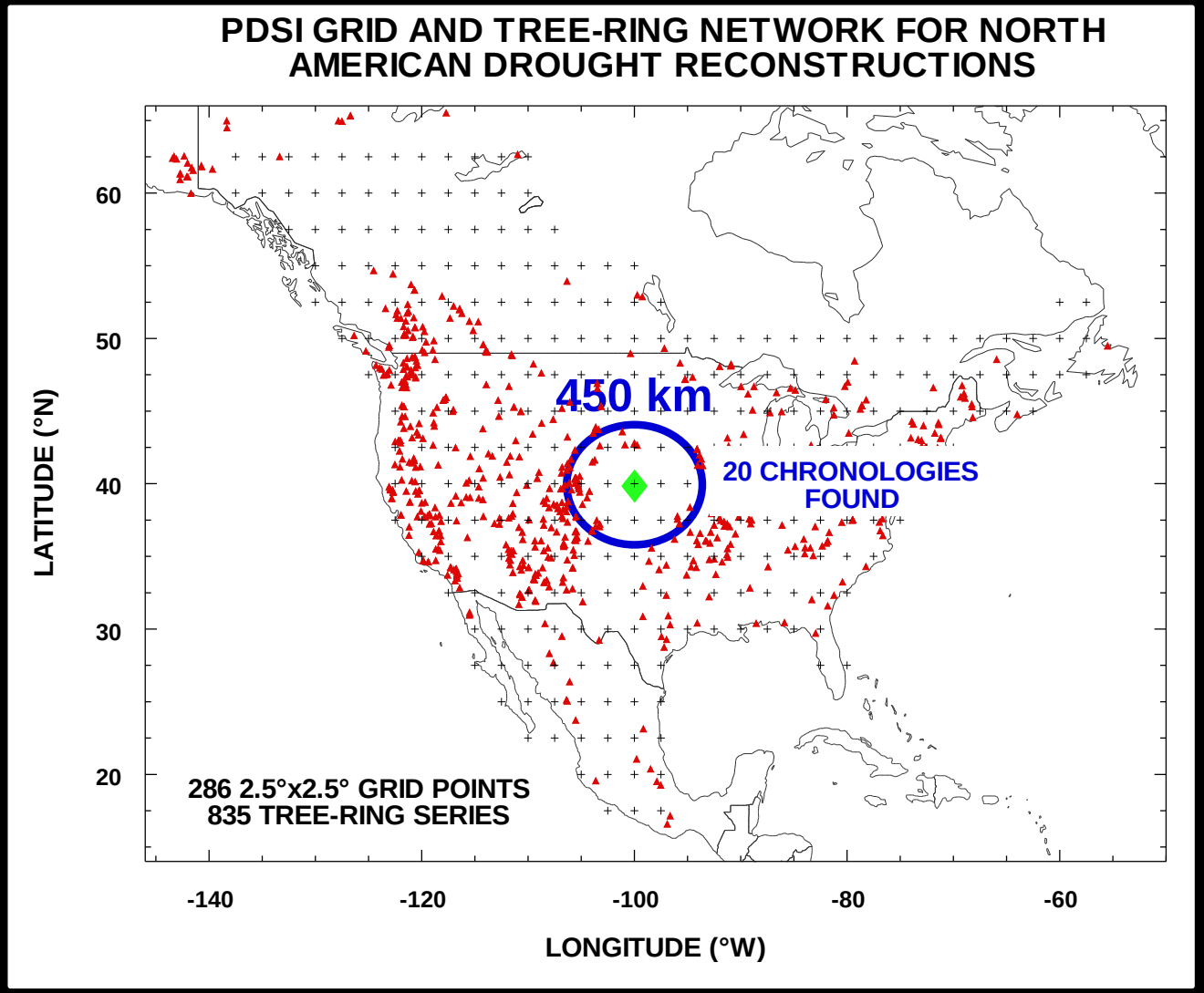
Stahle et al. 2011, *Geophysical Research Letters*

Instrumental Palmer Drought Severity Index



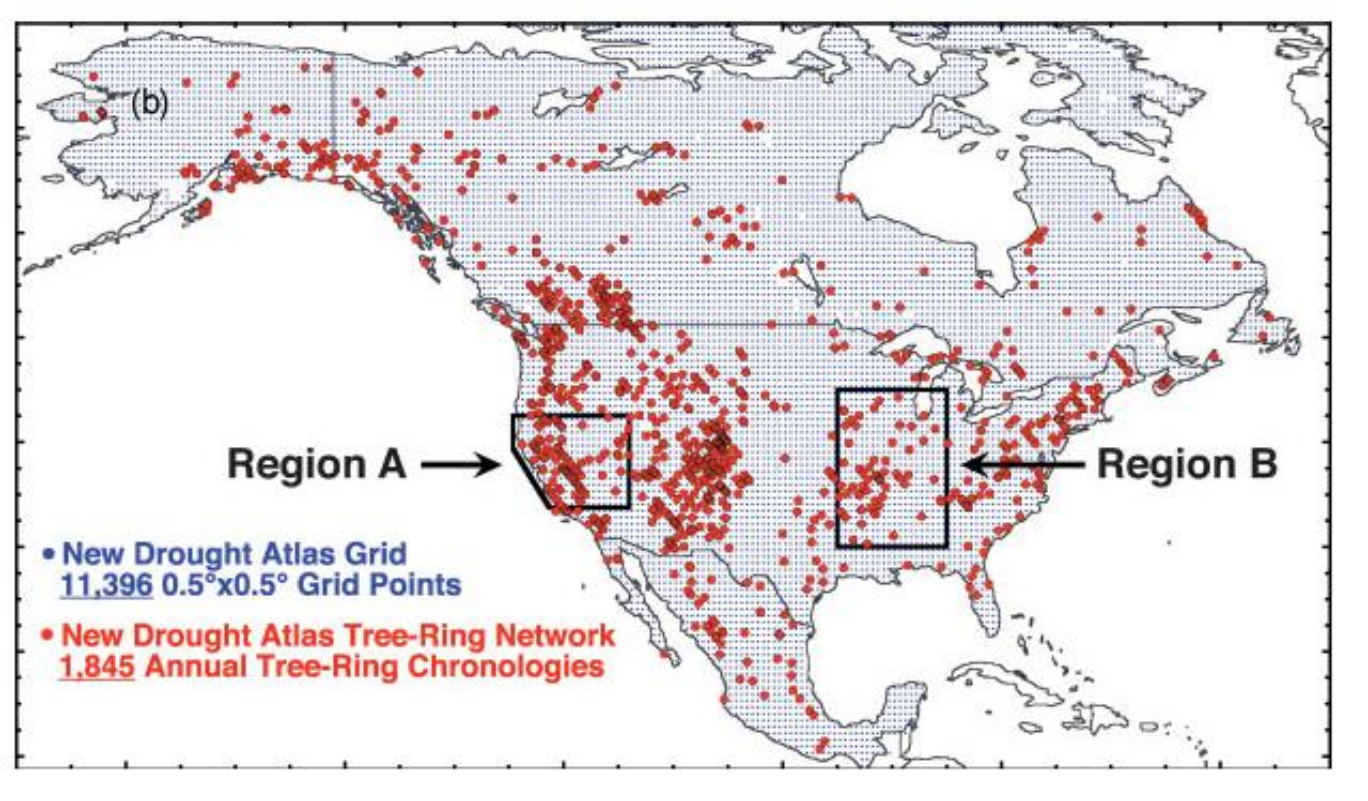
June-August
1933-1940

Original North American Drought Atlas (1999)



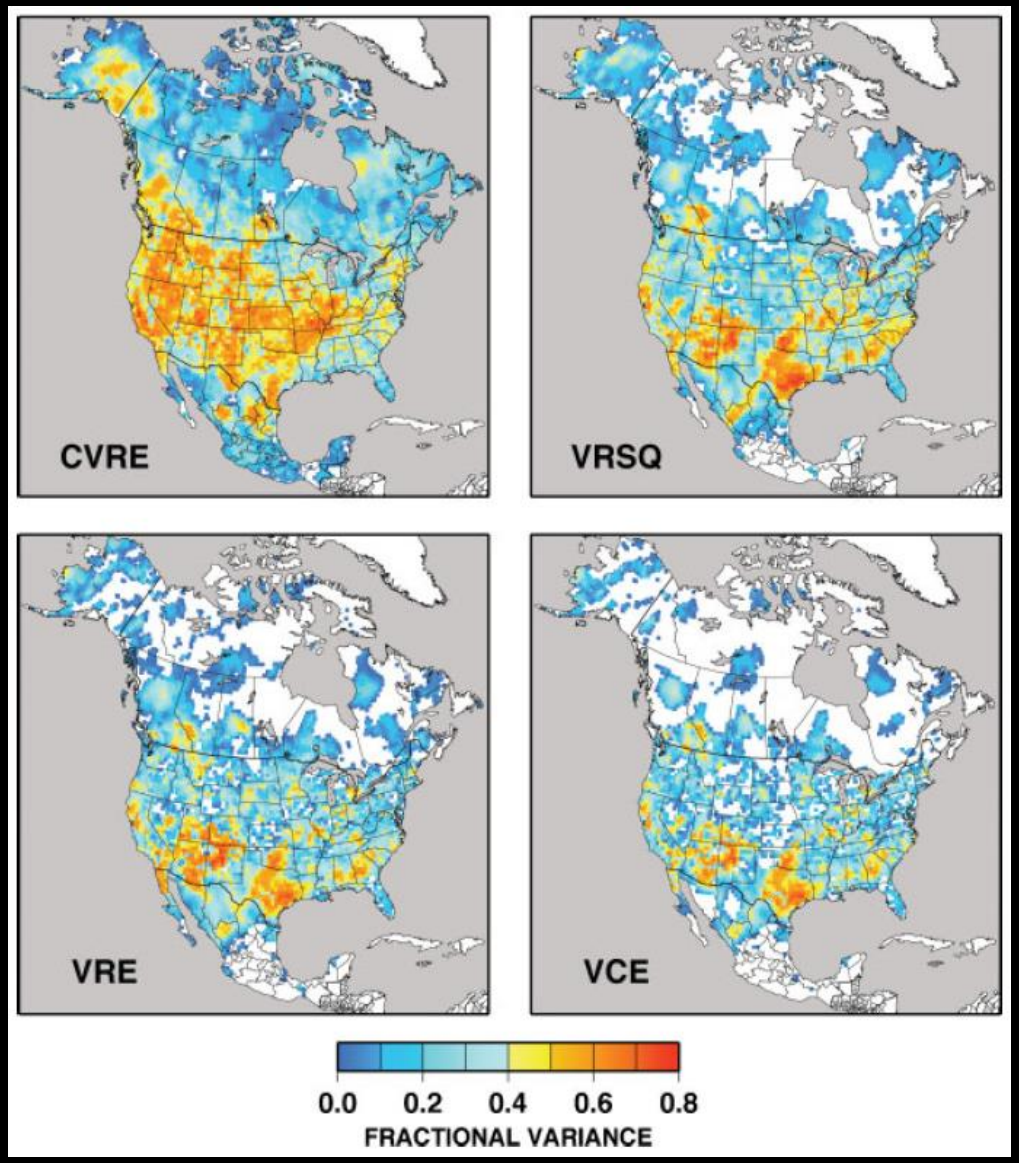
From Ed Cook

Current North American Drought Atlas



From Cook et al. (2010), *Journal of Quaternary Science*

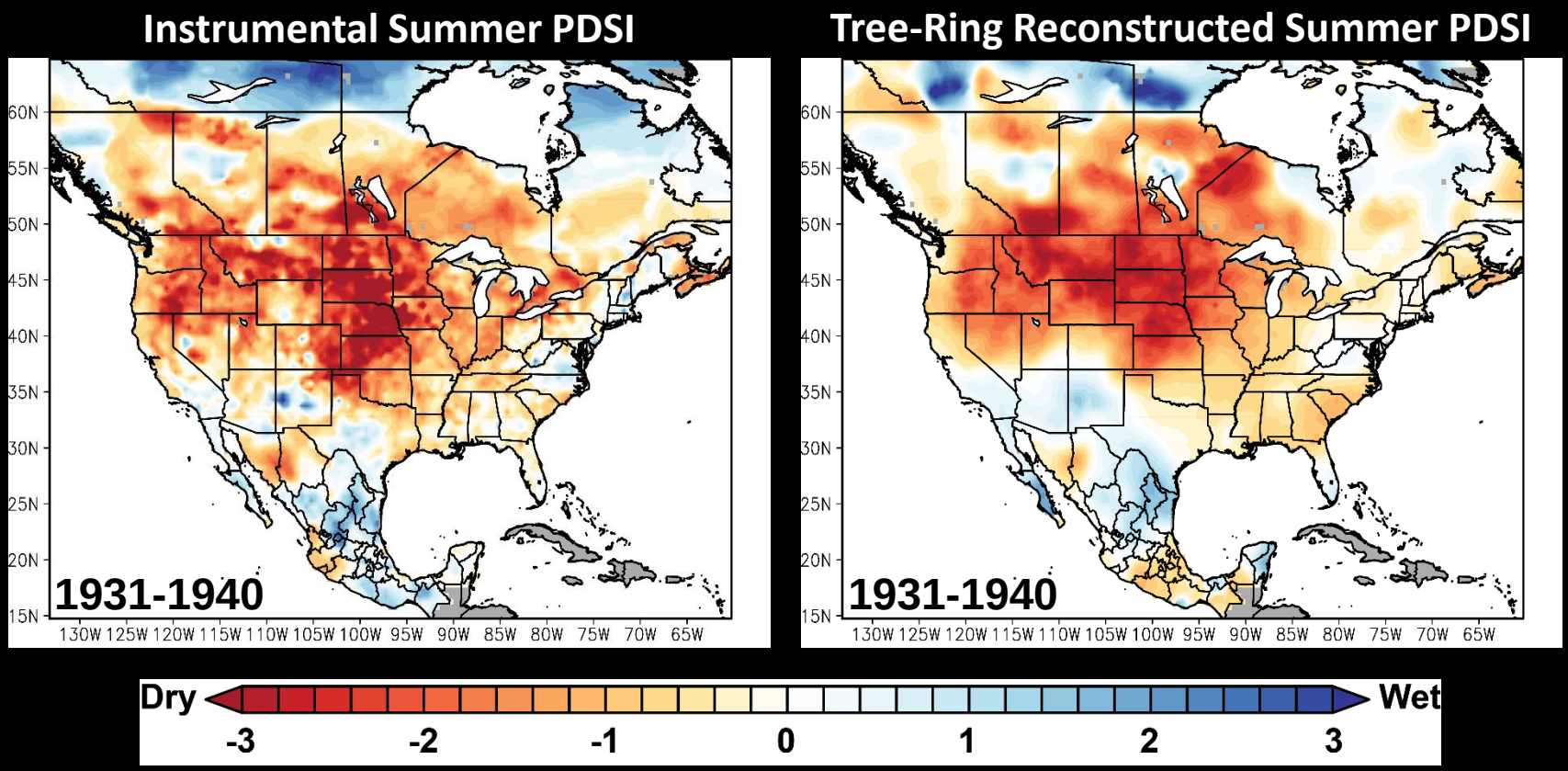
Current North American Drought Atlas



- Calibration: 1928-1978
- Verification: 1895-1927

From Cook et al. (2010), *Journal of Quaternary Science*

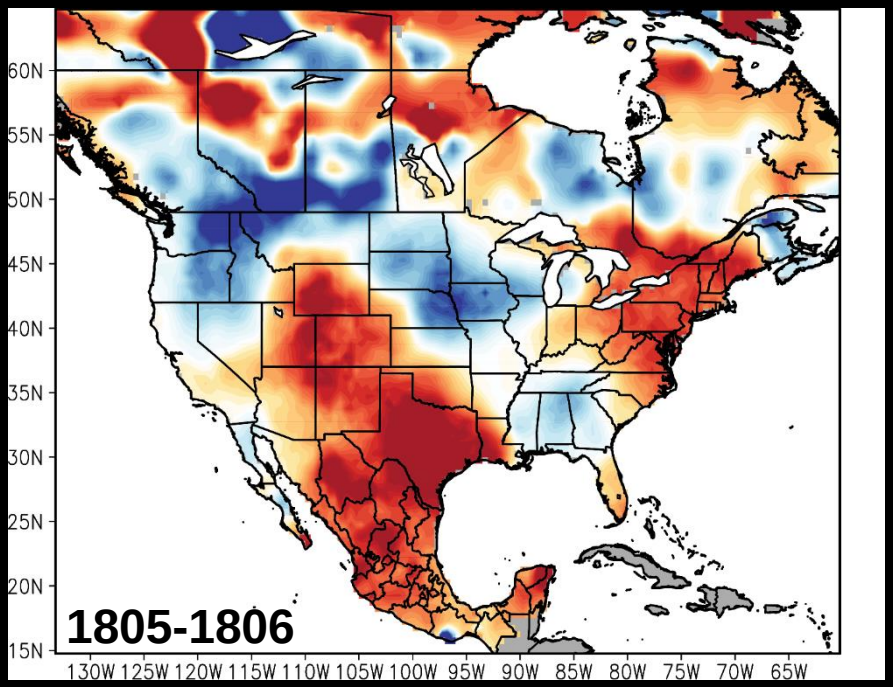
Current North American Drought Atlas



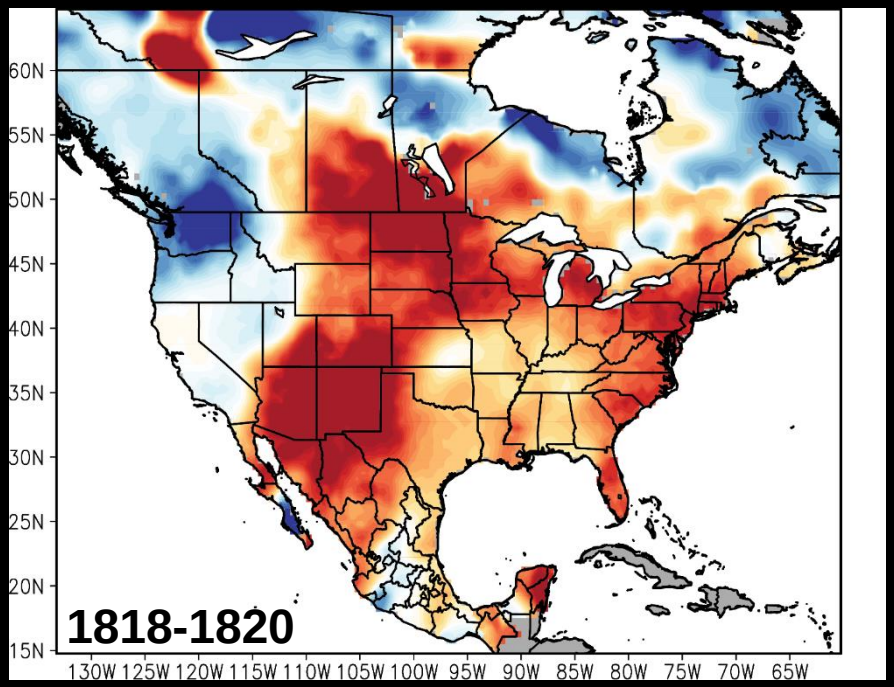
- "Reality check" of the tree-ring reconstructions vs. real instrumental data shows a similar "footprint"

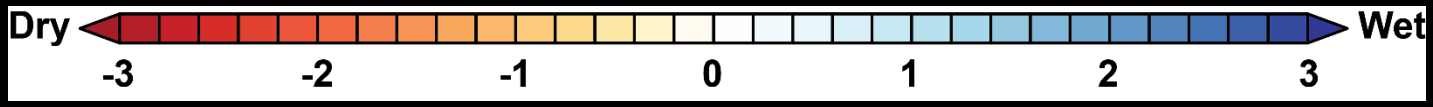
Current North American Drought Atlas

Pike Expedition, Summer PDSI



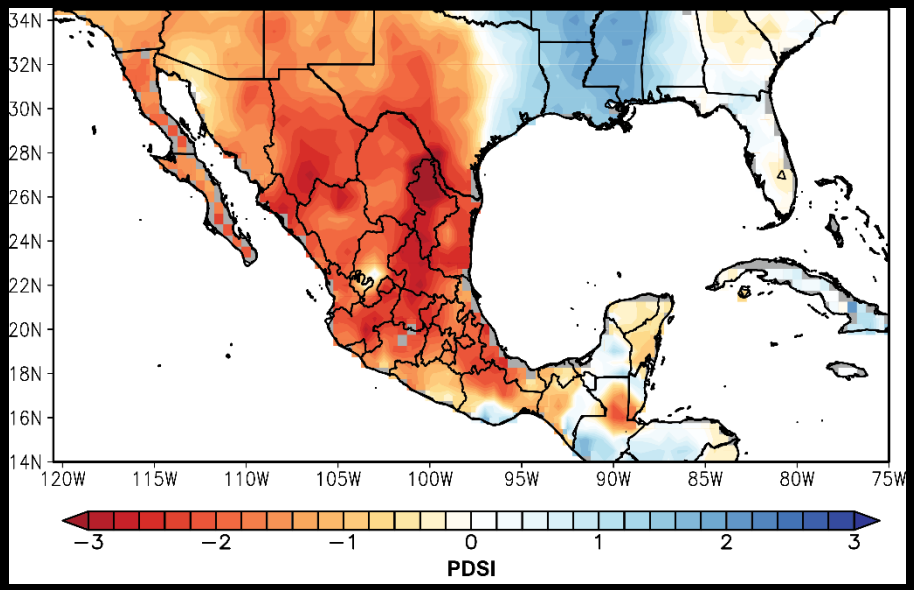
Long Expedition, Summer PDSI





- Zebulon Pike (1806-1807) "These vast plains of the western hemisphere, may become in time equally celebrated as the sandy deserts of Africa."
- Stephen H. Long (1820) labeled the central Great Plains as "the Great American Desert." The region "is almost wholly unfit for cultivation…the scarcity of wood and water, almost uniformly prevalent, will prove an insuperable obstacle in the way of settling the country."

Tree-Ring Drought Atlas Portal

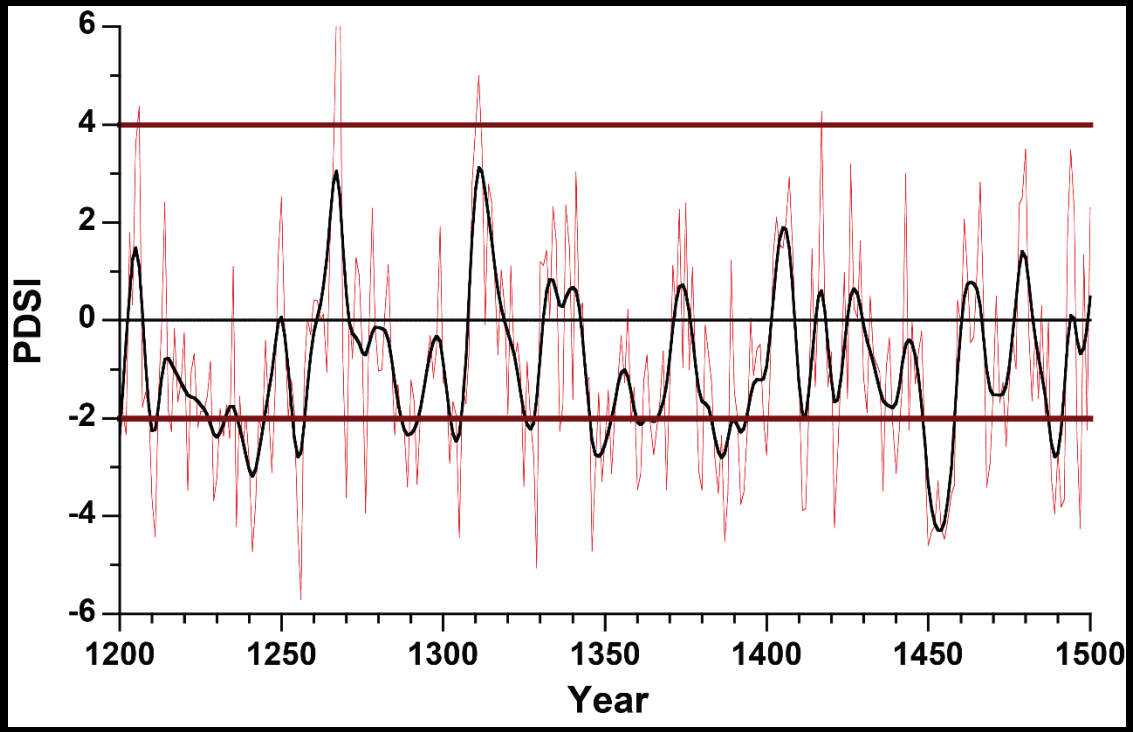


Spanish Conquest Drought
June-August PDSI 1521-1524
Mexican Drought Atlas

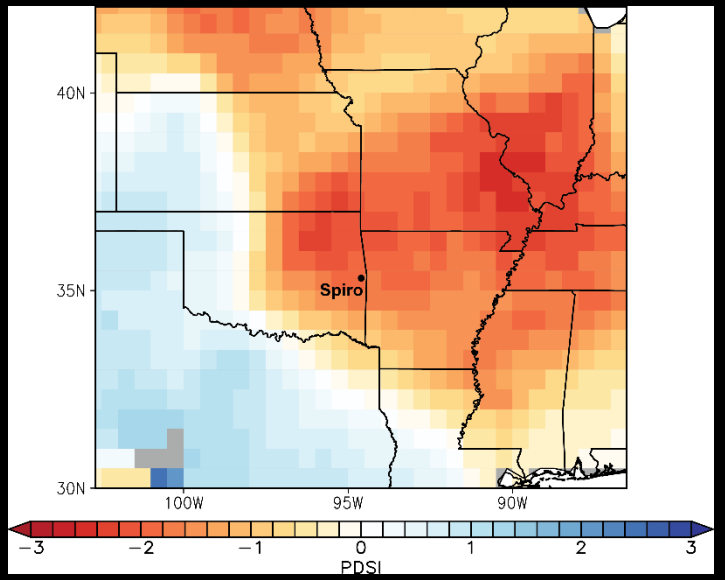
Burnette (2021, *Bulletin of the American Meteorological Society*)

- Suite of user-friendly webtools for all tree-ring reconstructed drought atlases
- Eastern Australia and New Zealand, Europe, Russia, Mexico, Monsoon Asia, North America, South America
- drought.memphis.edu

Spiro Drought Reconstruction



Spiro Grid Point
June-August Reconstruction
Dark Red Lines = Failed Harvest Threshold

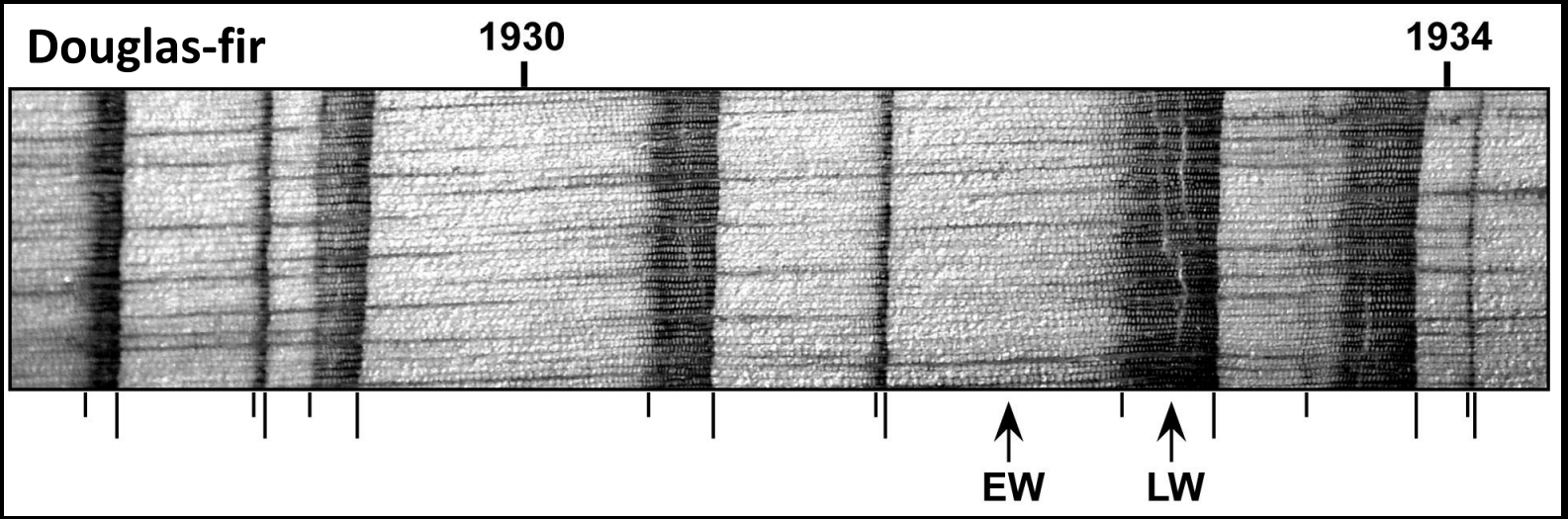


June-August PDSI Composite
1378-1401

From 1344-1400 = 23 years with PDSI ≤ -2 (failed harvest)

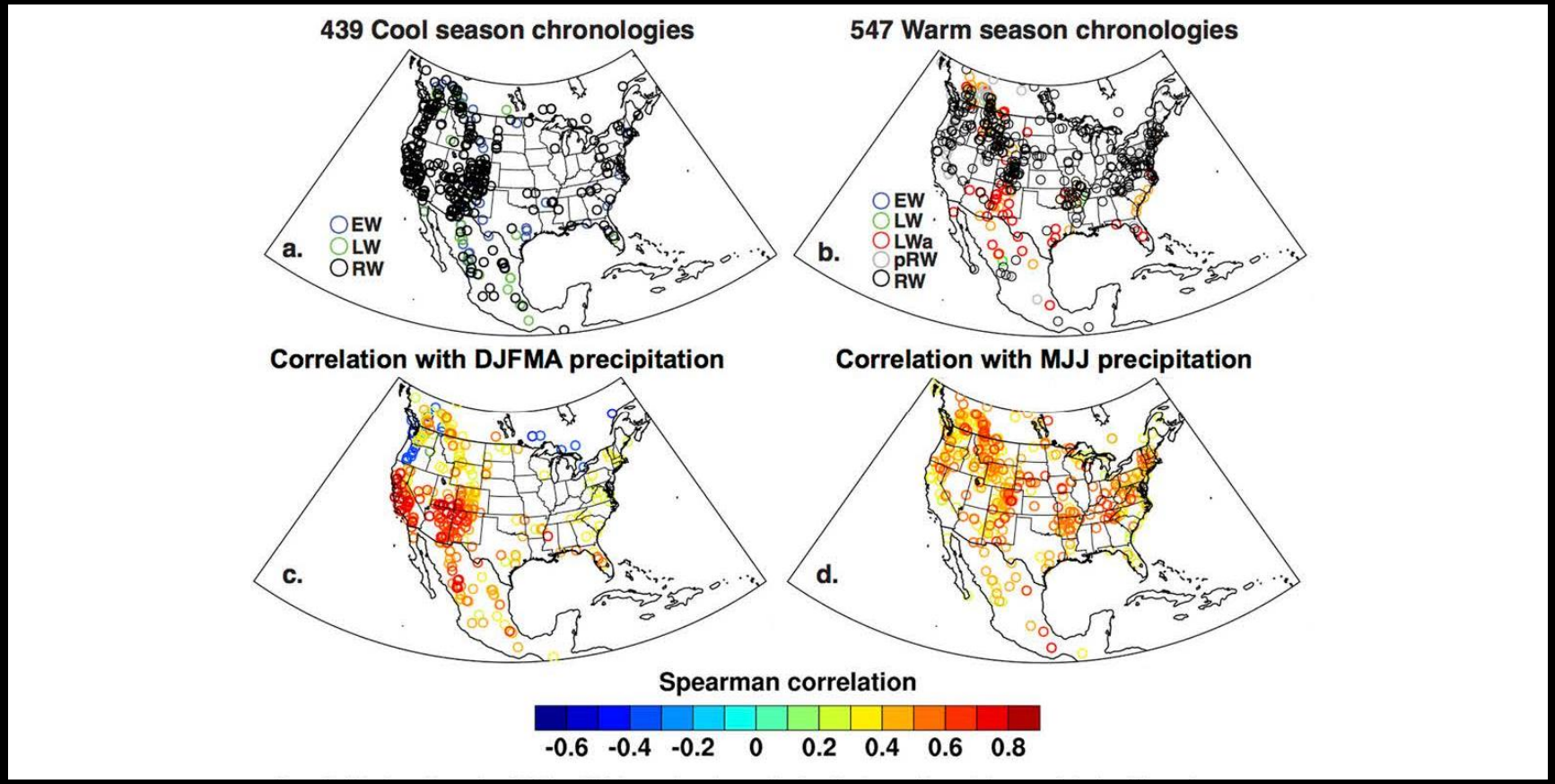
Burnette et al. (2020): Climate change, ritual practice, and weather deities at Spiro.
Recovering Ancient Spiro: Native American Art, Ritual, and Cosmic Renewal.

Earlywood and Latewood



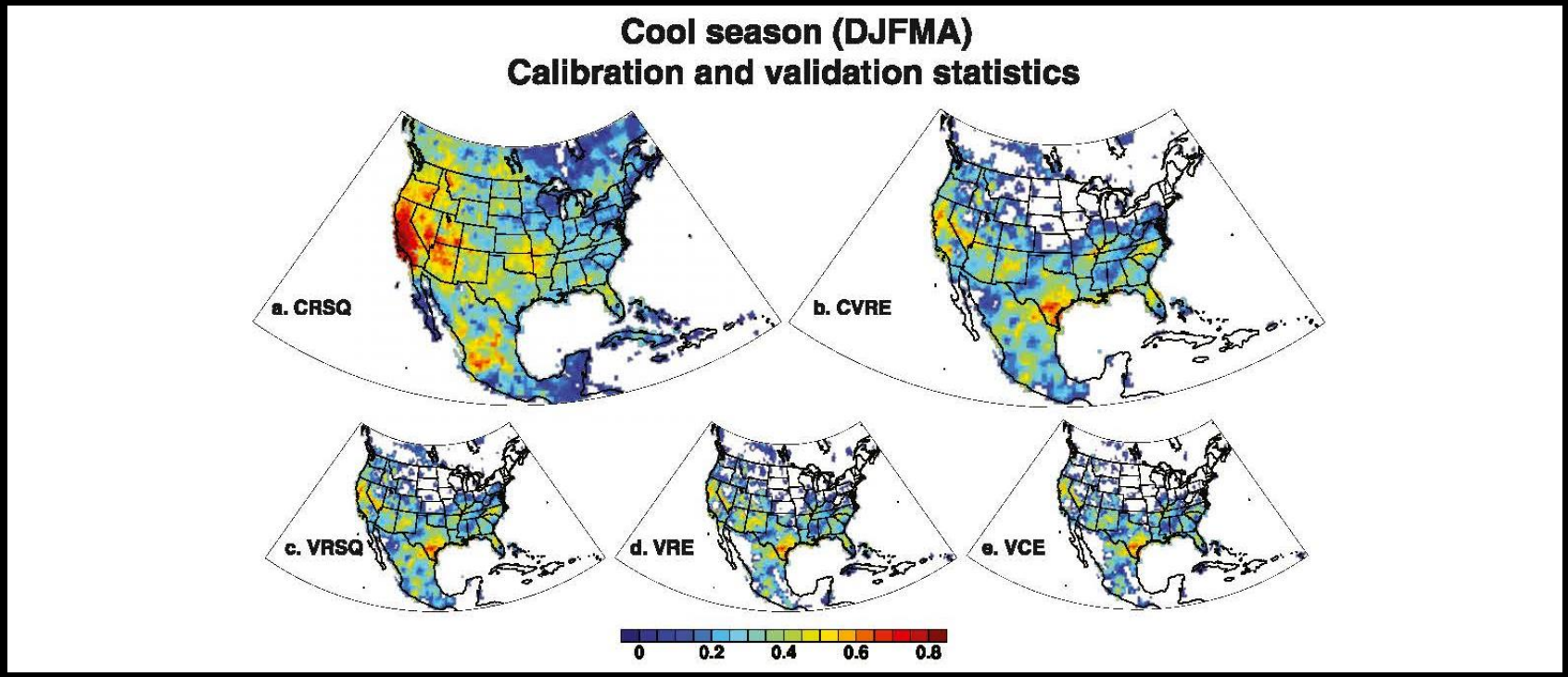
- Annual Ring = Earlywood (EW) + Latewood (LW) couplet

North American Seasonal Drought Atlas?



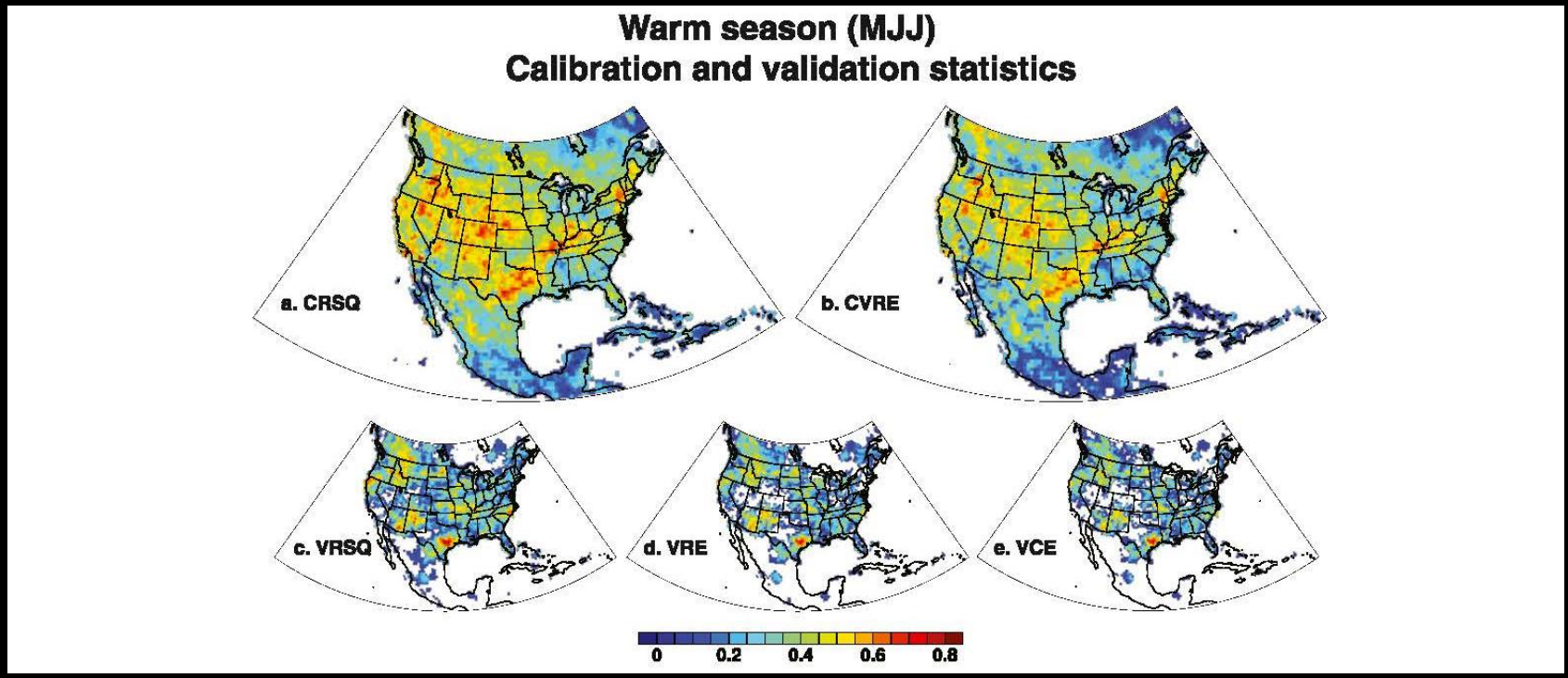
- What to reconstruct?
- How to screen?

North American Seasonal Precipitation Atlas



- Reconstruct seasonal precipitation totals

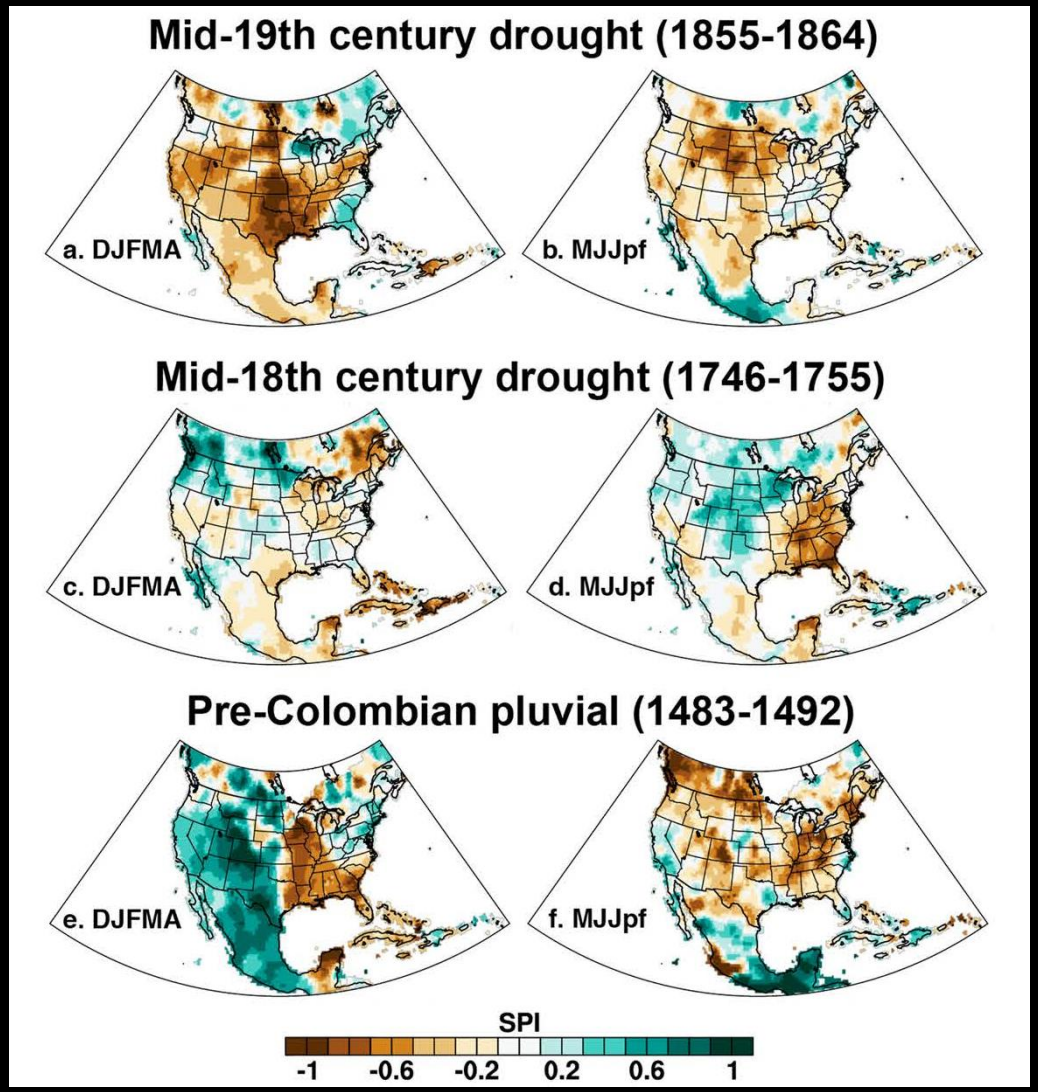
North American Seasonal Precipitation Atlas



- Reconstruct seasonal precipitation totals

North American Seasonal Precipitation Atlas

- How to show spatial drought?



How to Make Drought Atlases “Living”?

1. Simple attachment of the most recent data on to the end of the original reconstruction?
2. Regression of most recent gridded data on the original reconstruction?
3. Machine learning of the most recent gridded data on the original reconstruction?

Thank You

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- NSF Grants: AGS-1266015, AGS-2201584