Tree Rings, Climate Change and Impacts: Sketching a Research Agenda

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and
NBER

Acknowledgements: David Stahle and Henri Grissino-Mayer

Outline

- Instrument record
- Measuring Drought
- Dendochronology: Tree-Ring Analysis
  - History, Cross dating, Basic principles
- Reconstructing the Palmer Drought Severity Index (PDSI)
- The Reconstructions
- Applications to the Past

Milestones in Instrument Records

- Mid 1600s. Invention of thermometer (or thermoscope)
- 1714. Daniel Fahrenheit invented the first mercury thermometer
- 1722. Beginning of systematic recordkeeping in Uppsala
  - Erik Burman assisted by Anders Celsius (1701-1744)
  - Daniel Farenheit proposed his scale in 1724
- Rain gauge. Ancient Greeks used bowls to measure rainfall
- 1662. Christopher Wren. Tipping bucket rain gauge, called a pluviometer
- 1722. Reverend Horsley invented the modern rain gauge, consisting of a funnel placed at the top of a cylinder
- 1849. Smithsonian Institution created an observation network
- By 1900 many countries had created national meteorological services

Assessing Drought: Supply and Demand

- Early 1900s example: 21+ days with rainfall less than 1/3 of normal
- Thornthwait (1931) formalized evapotranspiration
- Palmer (1965) water balance concept, and alternative time scales
  - Palmer Hydrological Drought Index: groundwater, stream flow, 1 yr. + horizon
  - Palmer Drought Severity Index, ~ 9 month horizon
  - Palmer Z index measures moisture anomaly for a particular month
  - Crop Moisture Index, Palmer (1968), monitors short-term (weekly) conditions
- Standardized Precipitation Index (SPI), McKee et al. (1993)
  - Imposes a normal distribution on rainfall, multiple time scales
- Surface Water Supply Index, Wilhite and Glantz (1985)
  - Calculated at the river basin level; includes snowpack, reservoir storage, stream flow and precipitation
- Vegetation Condition Index, Kogan (1995)
  - Computed from satellite images

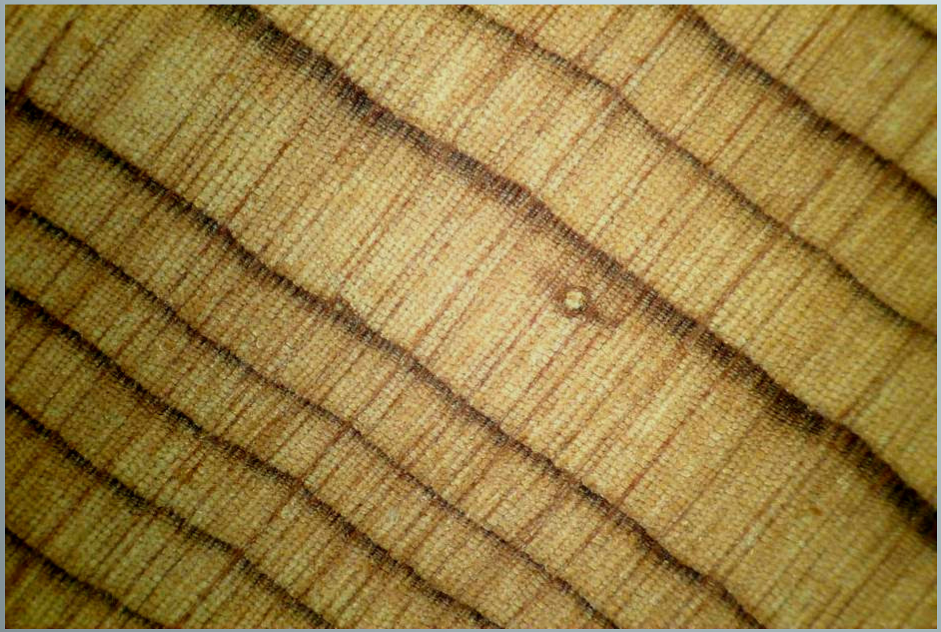
Hein, "A Review of Twentieth-Century Drought Indices" Bull Am Met Soc 83 (2002)

Palmer Drought Severity Index (PDSI)

- Oldest and most widely-used measure
  - Wayne C. Palmer, “Meterological Drought” (1965)
  - William M. Alley “The Palmer Drought Severity Index: Limitations and Assumptions,” J. of Applied Meteorology, 23 (1984)
- Water balance equation includes
  - rainfall, runoff, evaporation, transpiration, soil recharge
- Standardizes moisture conditions over time and space
- Range: -6 (extreme drought) to +6 (extremely wet); 0 = average
- Ignores: stream flow, reservoir levels, snowfall
- Less useful in mountain areas or regions of various microclimates
- Can be reconstructed or estimated from tree-ring chronologies

Dendochronology

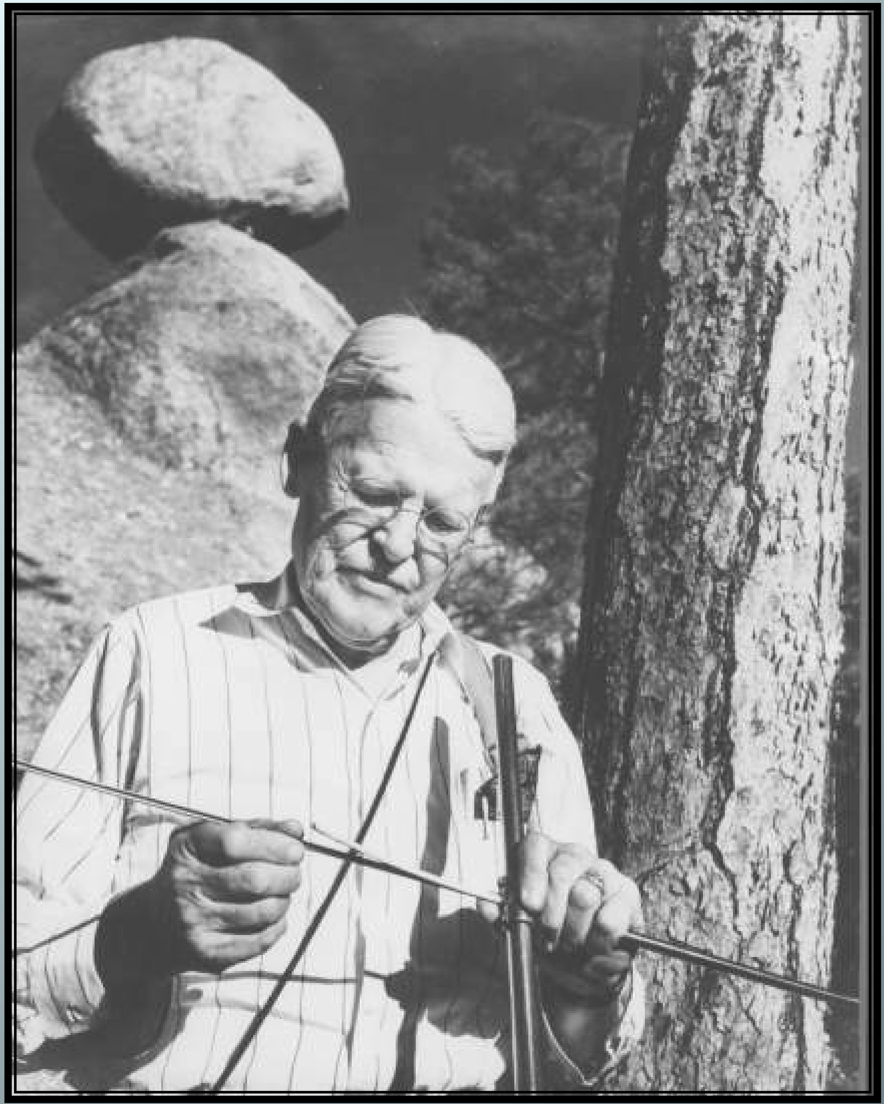
Leonardo da Vinci

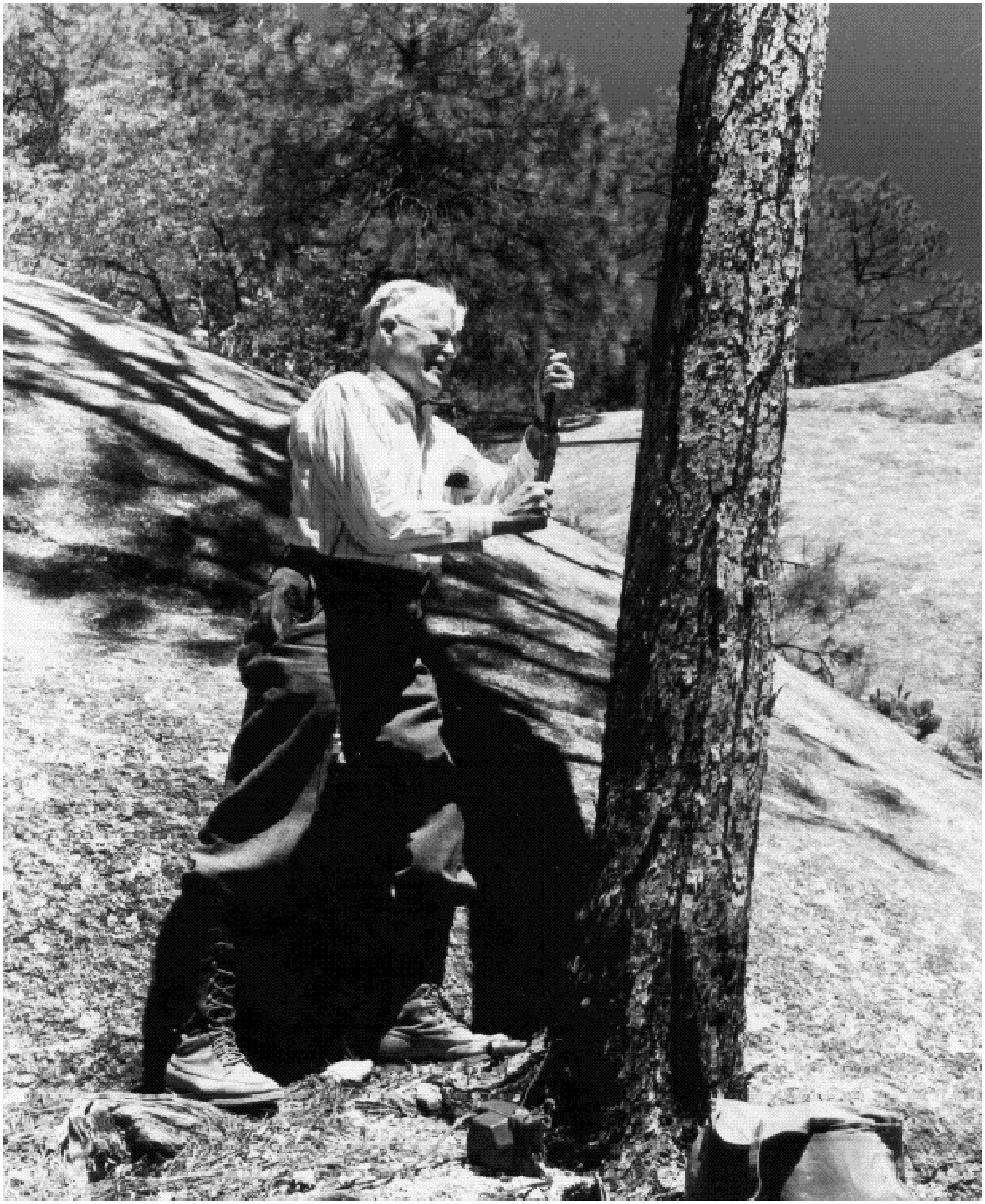


"Rings in the branches of sawed trees show the number of years and, according to their thickness, the years which were more or less dry. Thus, they reflect the individuals worlds to which they belong; in the north [of Italy] they are much thicker than in the south."

Andrew E. Douglass (1867-1962)
The modern founder of the field, he was a student of the famous astronomer Percival Lowell who, in 1894, sent Douglass across the country tobuild an observatory in Arizona. While acquiring the timber for the observatory's construction, Douglass noticed similar ring-width patterns in the stumps of the trees cut for construction.

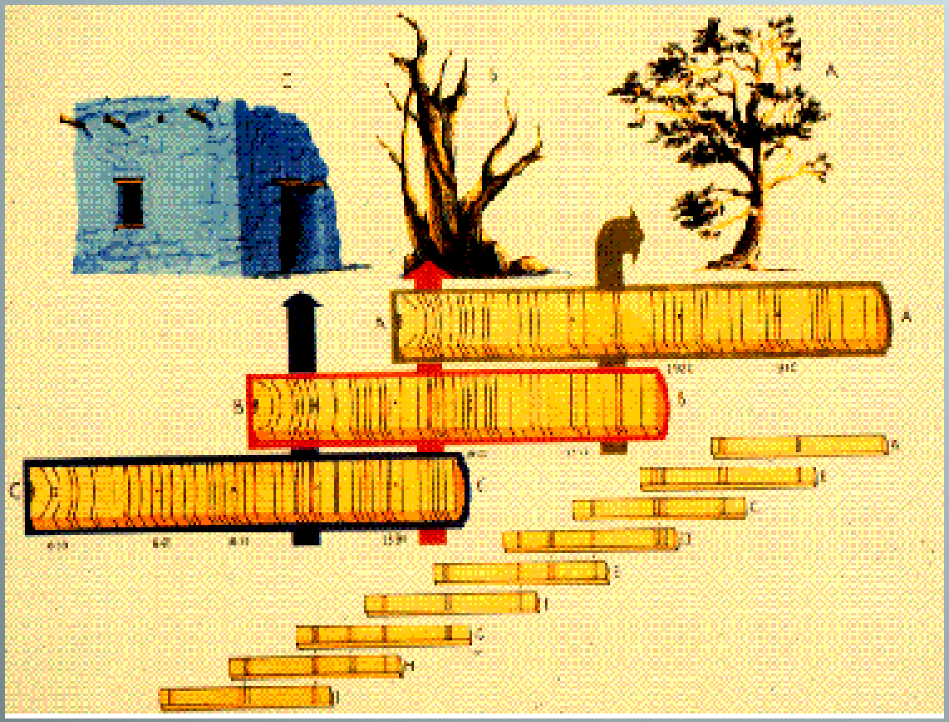
By the early 1920s, Douglass had pioneered the science of dendro-chronology, most importantly, the principle of cross dating.

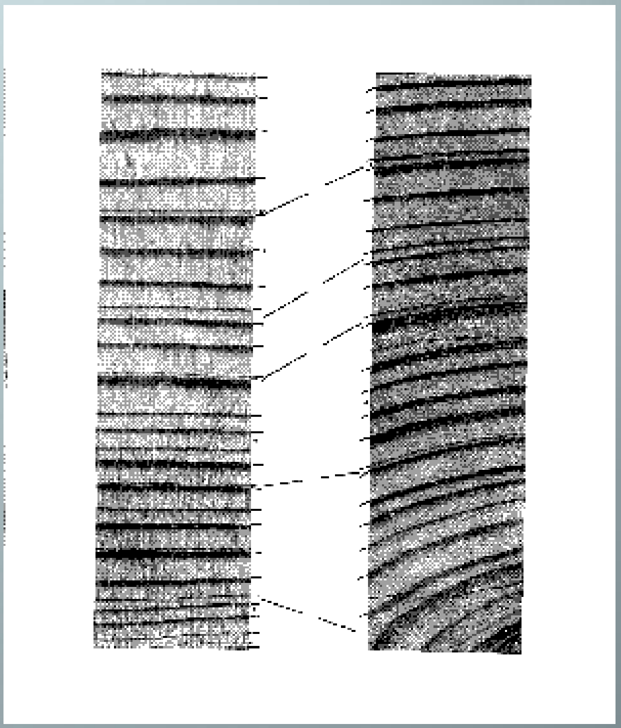




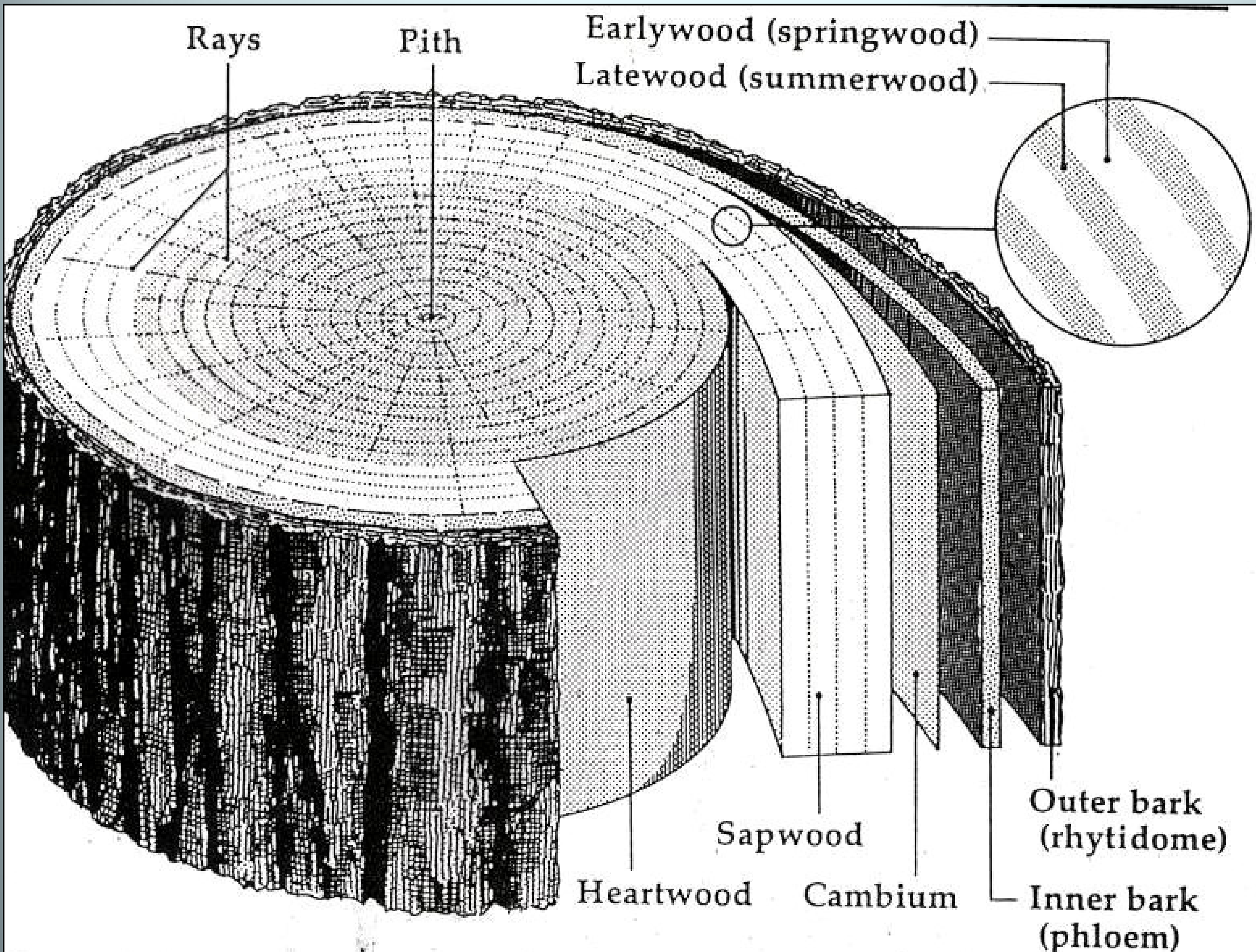
Andrew Ellicott Douglass
(1867–1962)

Cross dating

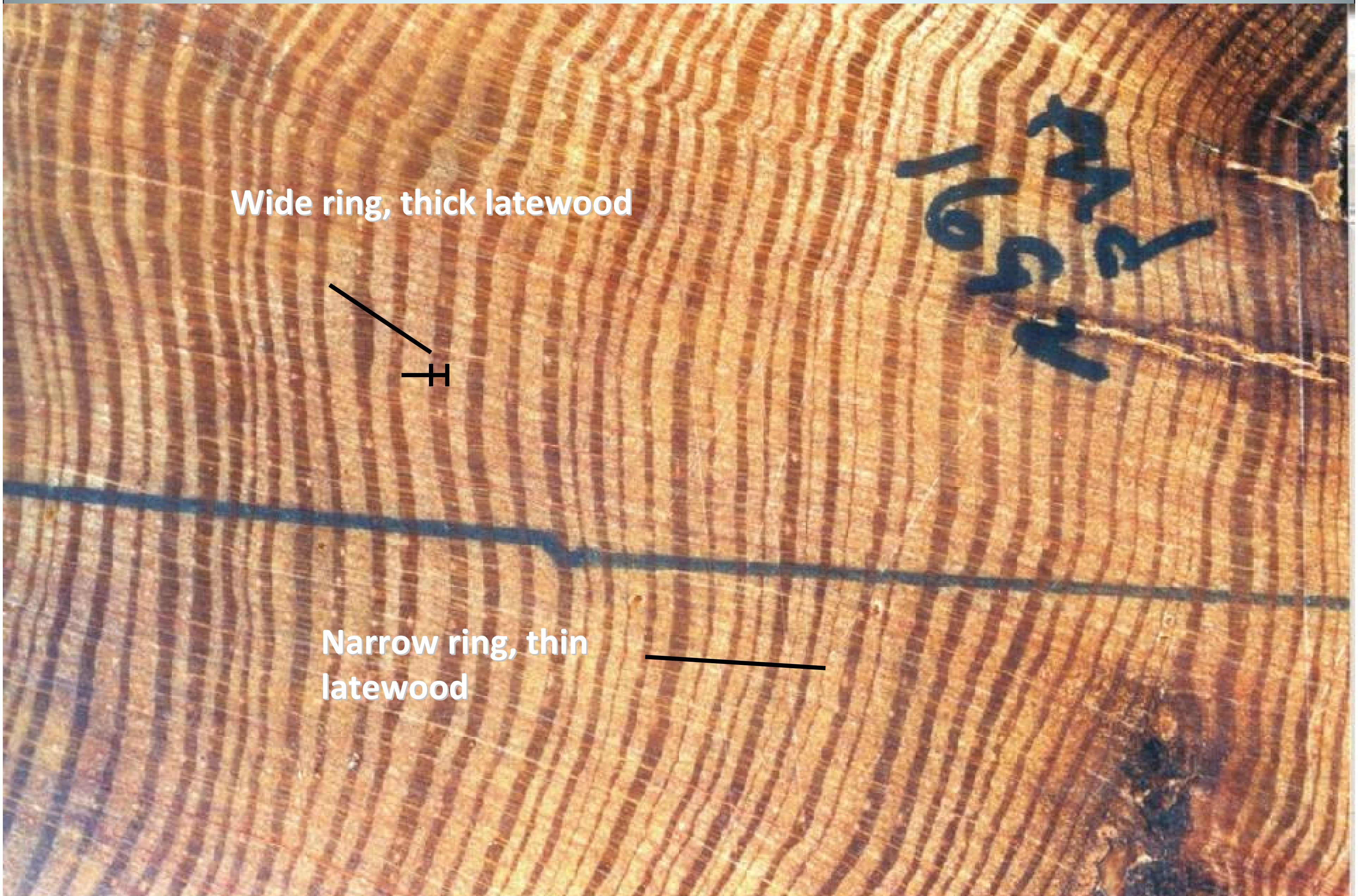




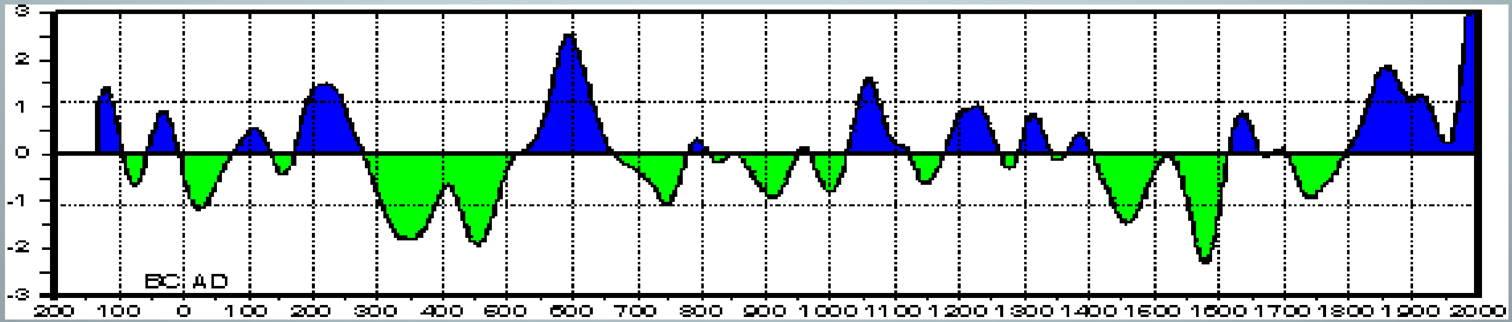
Pattern recognition done by experienced eyes. Missing rings & double rings limit usefulness of optical scanning software.



Portions of a tree trunk


Wide ring, thick latewood
Narrow ring, thin
latewood

1. Uniformitarianism Principle



Future?

Past

Present

Assumes that climatic processes operating today were operating similarly in the past.

2. Limiting Factors

- Genetic potential

  Determines the environments the tree will tolerate and the response the tree will make to these environments

- Nutrients
- Moisture
- Radiant energy

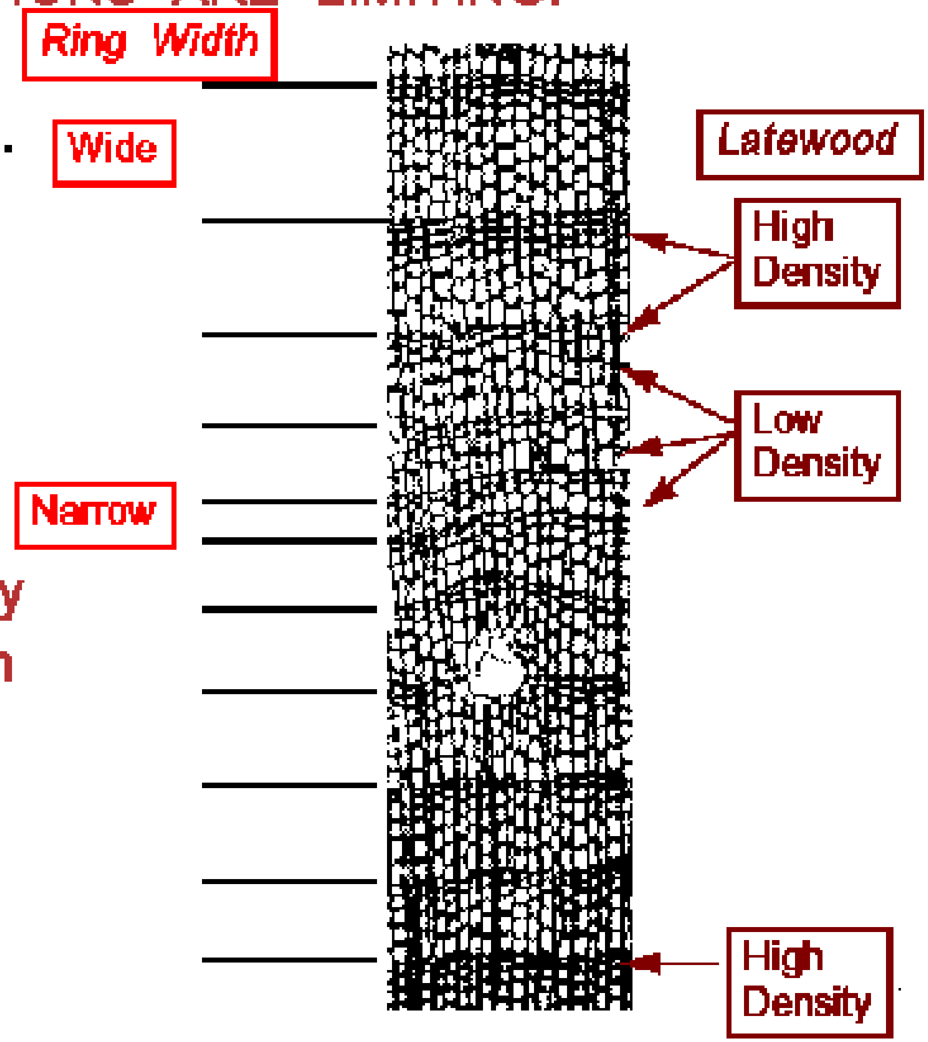
WHEN CONDITIONS ARE LIMITING:

Many growth-related processes are limited.

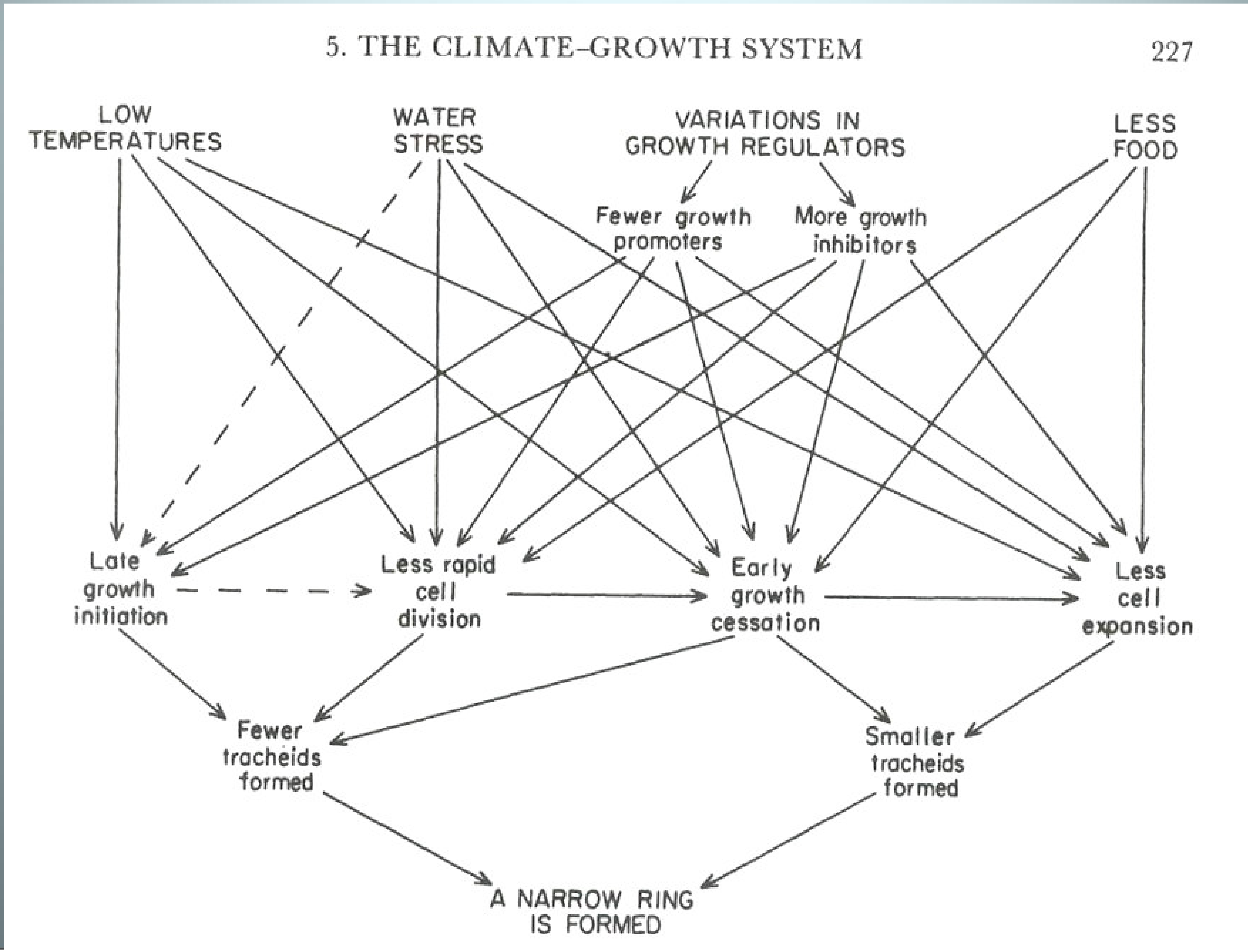
Fewer cells are produced.

Rings are narrow.

Cell characteristics and wood density vary depending upon when and what factors are limiting.



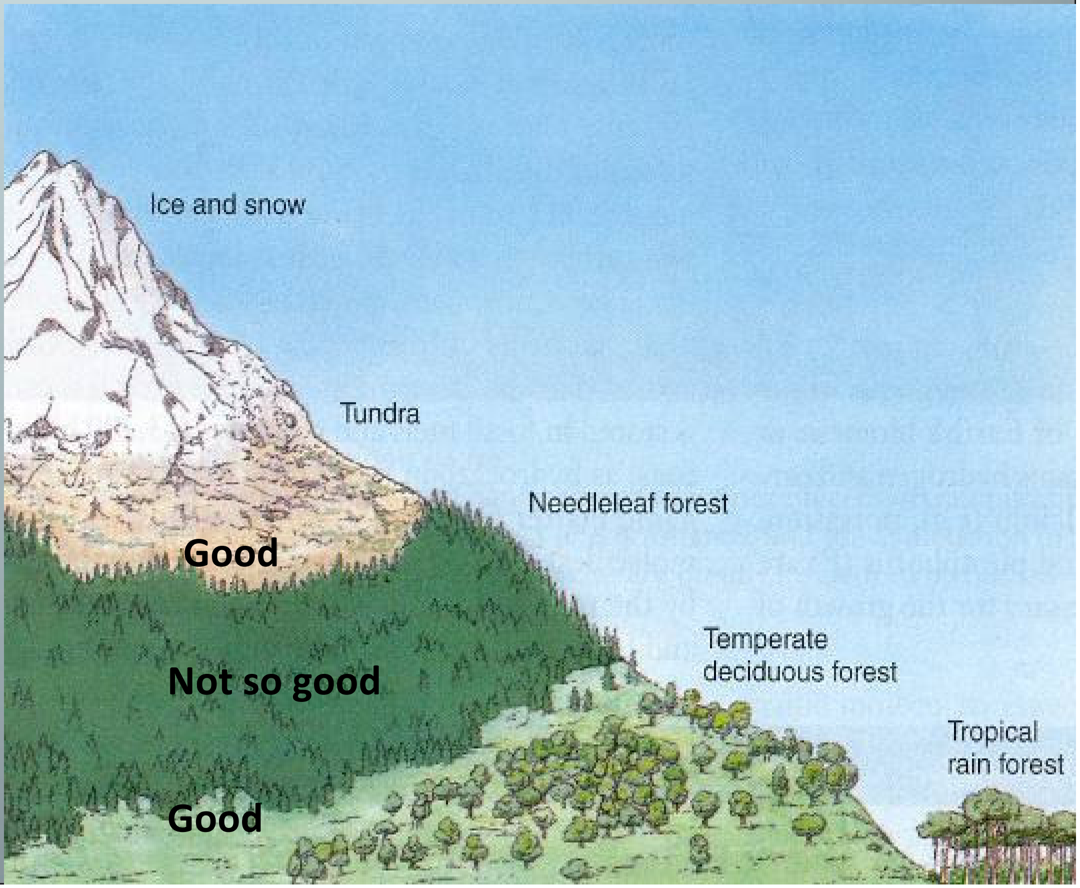
The basic model:



3. Ecological Amplitude

- A tree species will be more responsive and sensitive to changes in environmental conditions in the outer limits of its range.

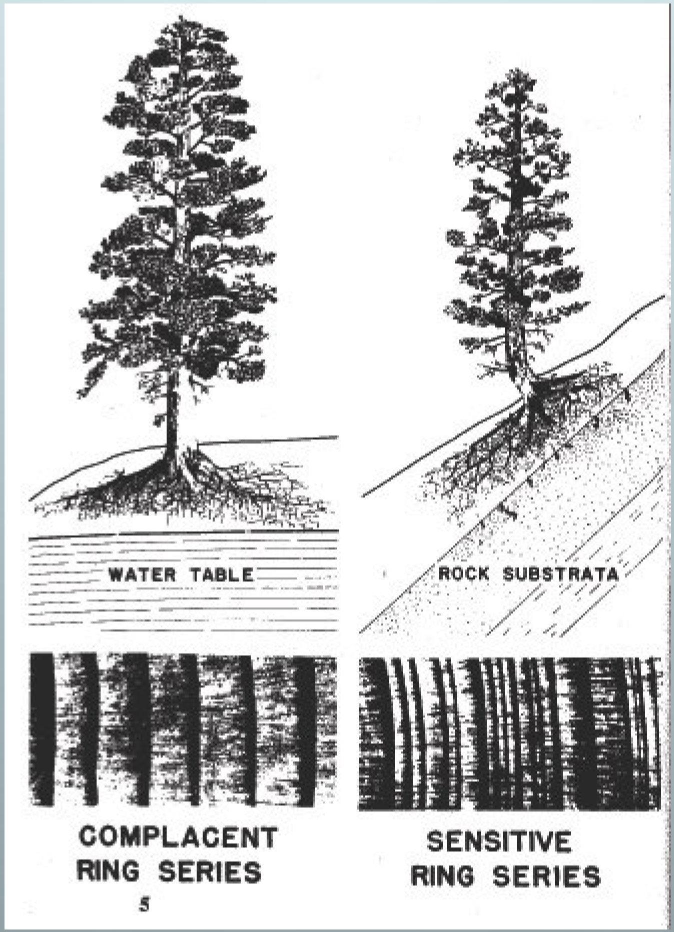
- Elevation matters



4. Principle of Site Selection

- Seek sites that will enhance a tree’s responsiveness to environmental factors.
- Select sites where factors are more limiting.
- The growth forms of trees provide clues where such sensitive sites exist.

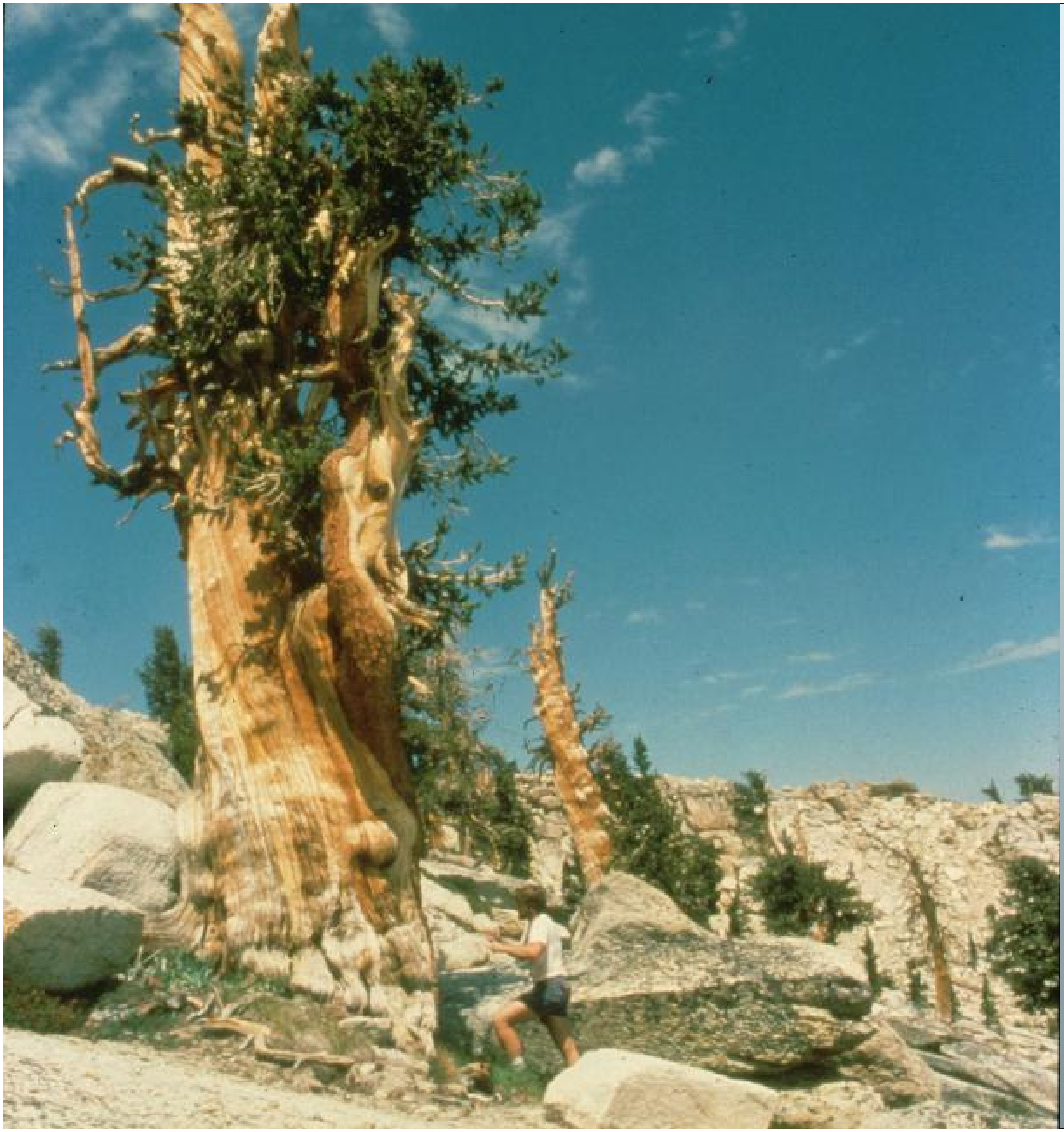
Complacent and Sensitive Ring Series



What to look for in trees that indicate longevity:

1. Dead spike top or broken top
2. Heavy, drooping lower limbs
3. Short stature, inverted carrots
4. Erratic growth forms
5. Stripbark
6. Sparse foliage in crown
7. Exposed roots
8. Isolated individuals

El Malpais National Monument, NM



Bristlecone pine

Alta Peak, Sierra Nevada, CA

5. Aggregate Tree Growth

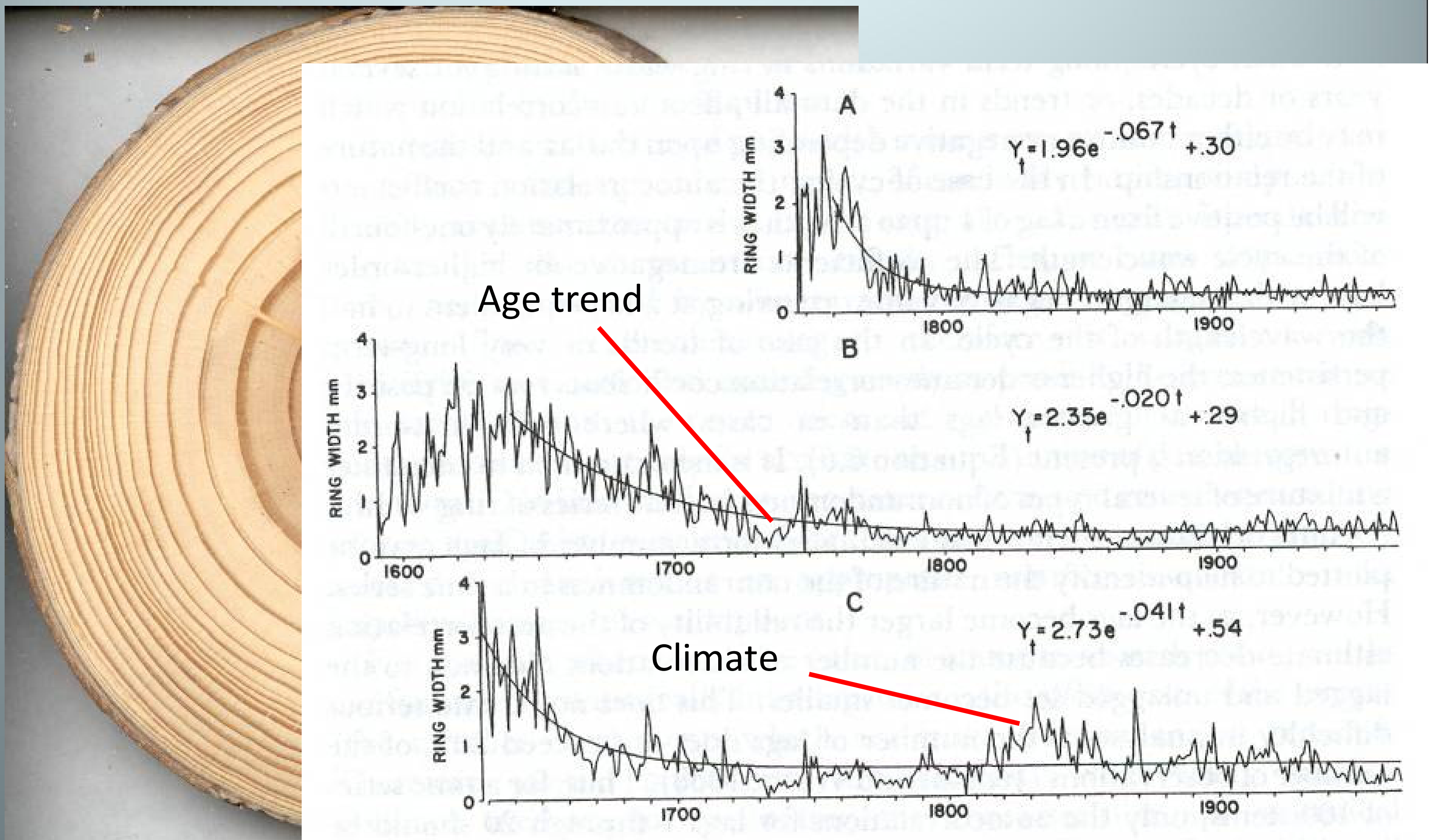
- Tree growth can be "decomposed" into five basic parts:

$$R_t = A_t + C_t + \delta D1_t + \delta D2_t + E_t$$

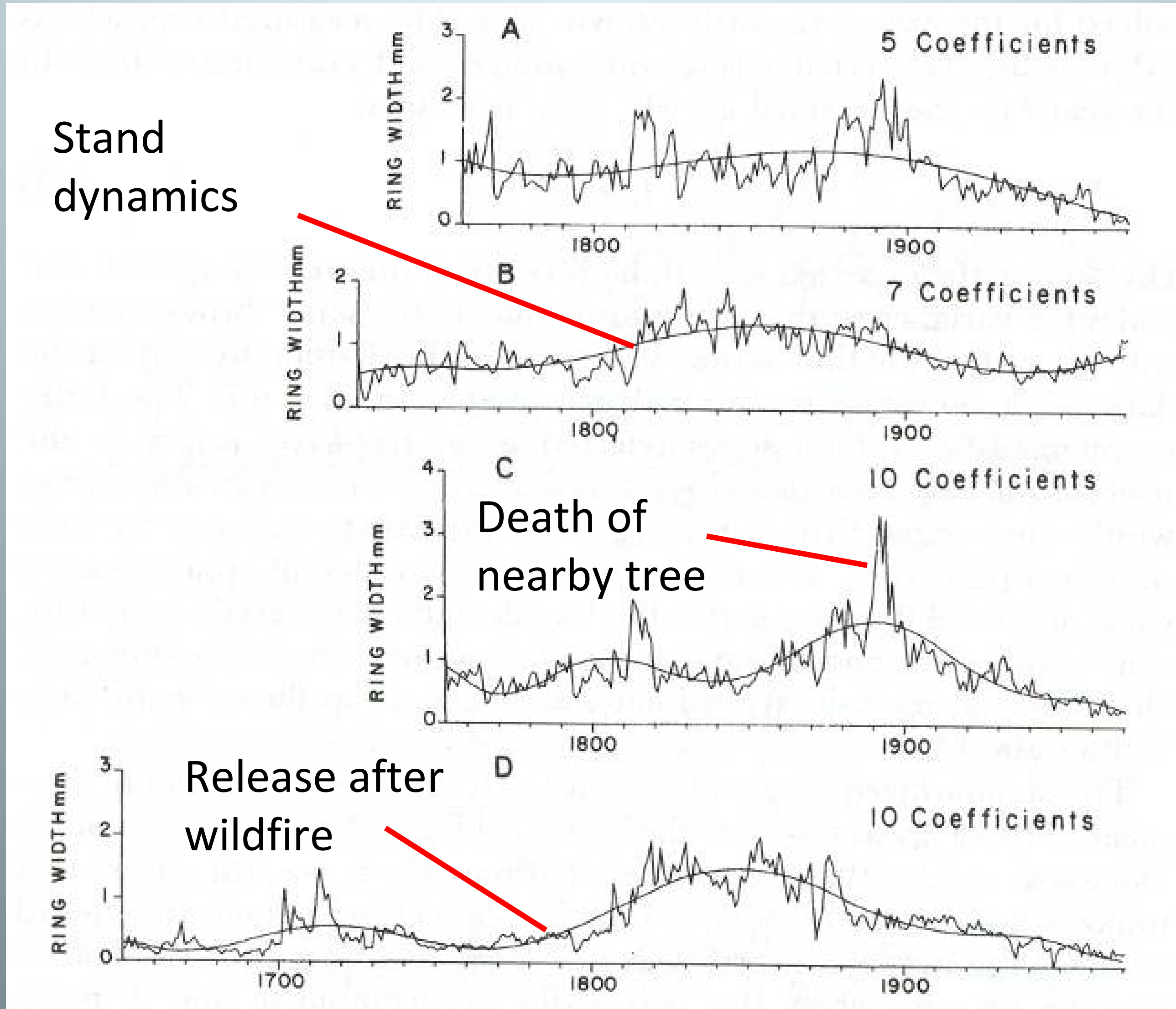
R = ring width, t = the current year, and delta = presence (1) or absence (0) indicator

1. A = age-related trend
2. C = climate
3. D1 = exogenous (external) disturbance processes
4. D2 = endogenous (internal) disturbance processes
5. E = random error
6. Climate is the desired goal, so mathematically remove other effects

5. Aggregate Tree Growth



5. Aggregate Tree Growth



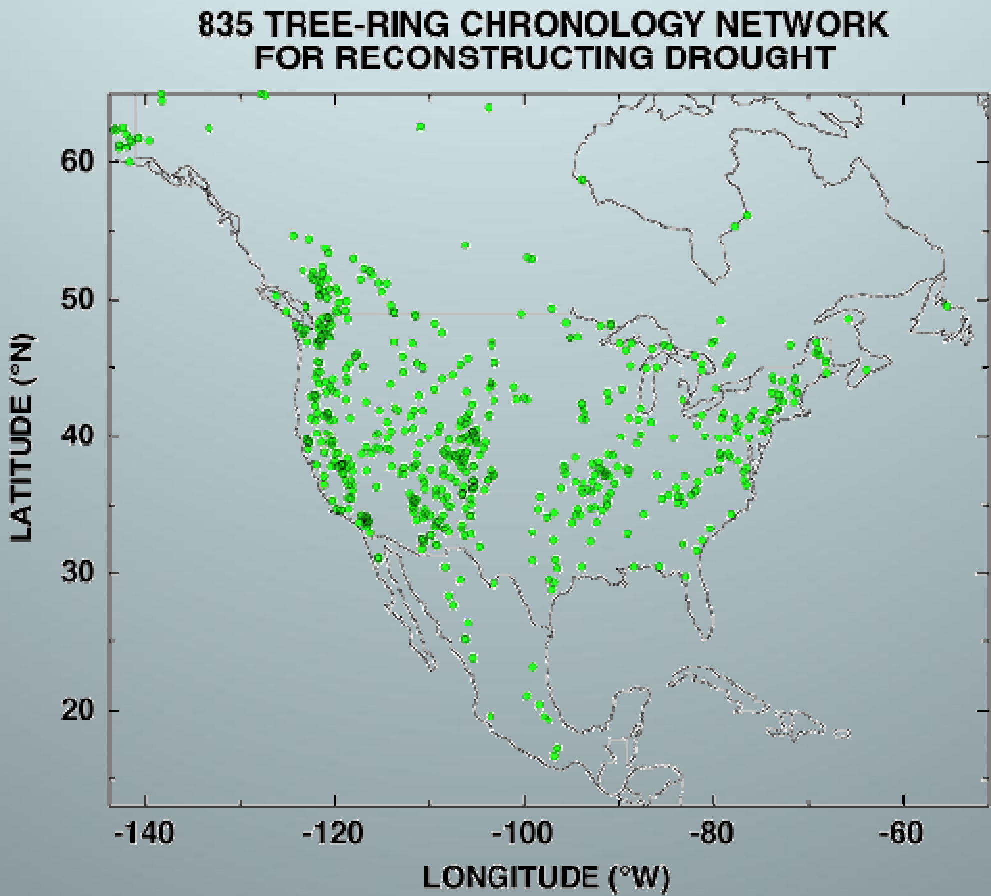
6. Principle of Replication

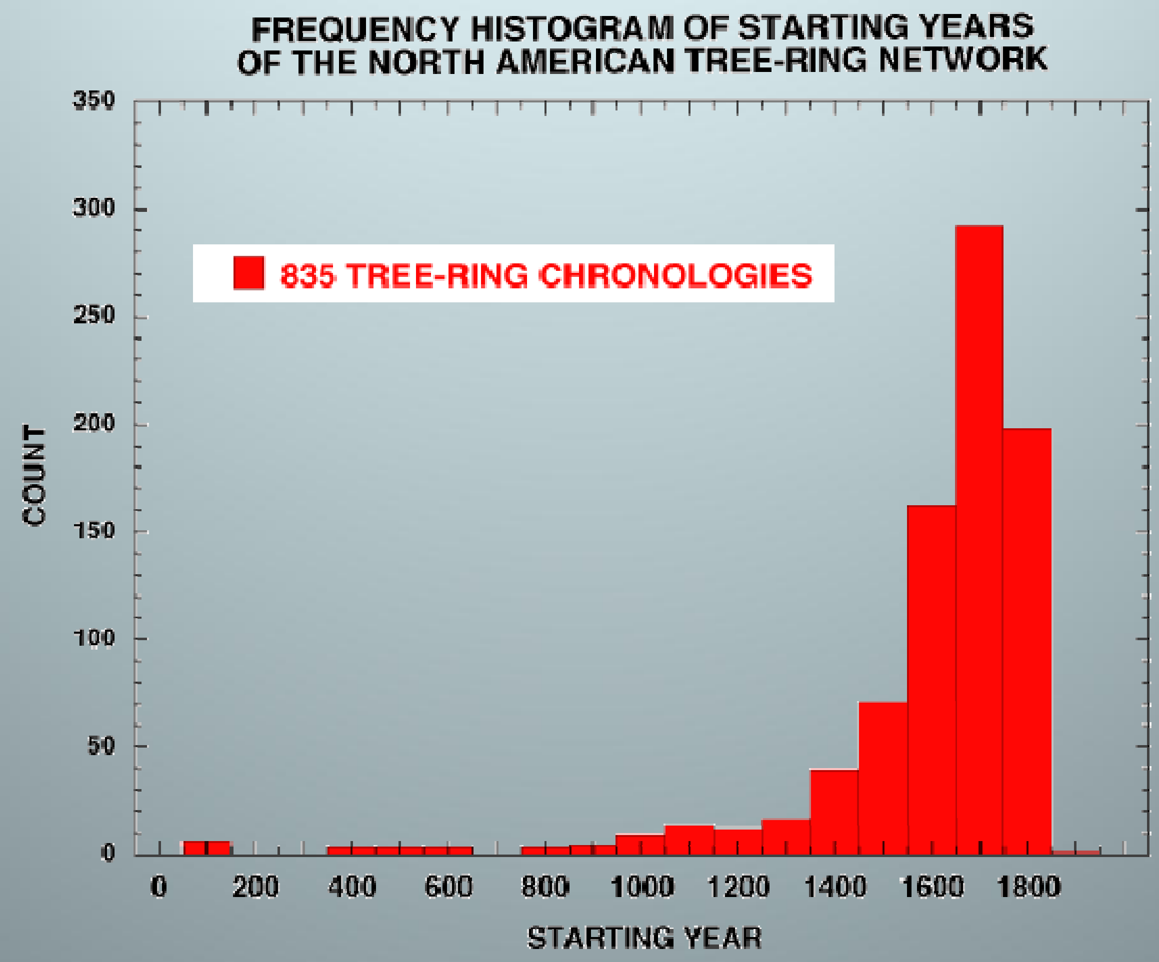
- Sample more than one stem radius per tree and more than one tree per site.
- Obtaining more than one increment core per tree reduces the amount of "intra-tree variability" = the amount of undesirable environmental signal peculiar to only that tree.
- Obtaining numerous trees from one site (and perhaps several sites in a region) ensures that the amount of "noise" is minimized.

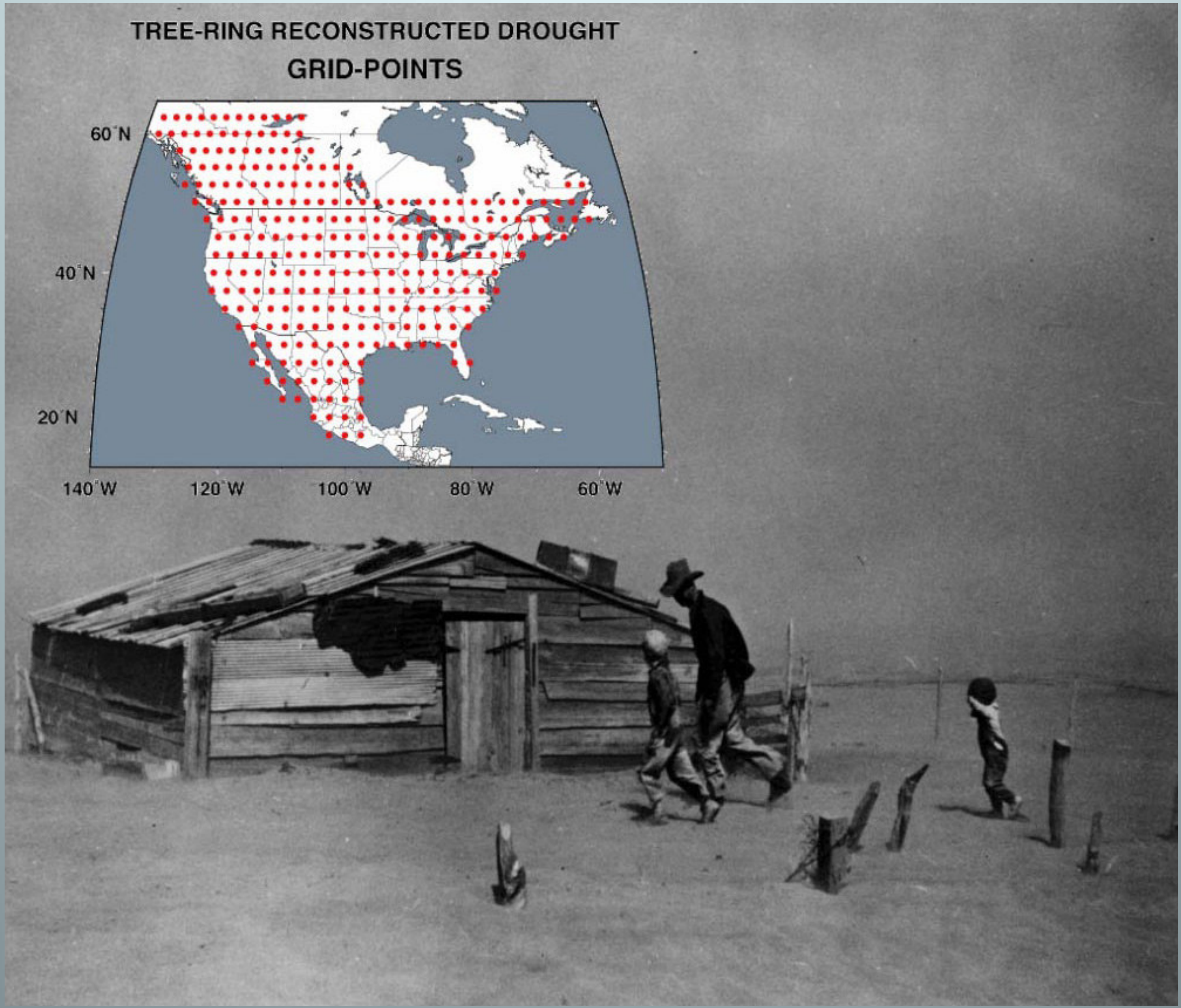
Reconstructing the PDSI

- Newly available
  - 835 exactly dated, annual tree-ring chronologies

- Cook, E.R. and P.J. Krusic. 2004. The North American Drought Atlas. Lamont-Doherty Earth Observatory and the National Science Foundation


835 TREE-RING CHRONOLOGY NETWORK
FOR RECONSTRUCTING DROUGHT
LATITUDE (°N)
60
50
40
30
20
-140
-120
-100
-80
-60
LONGITUDE (°W)

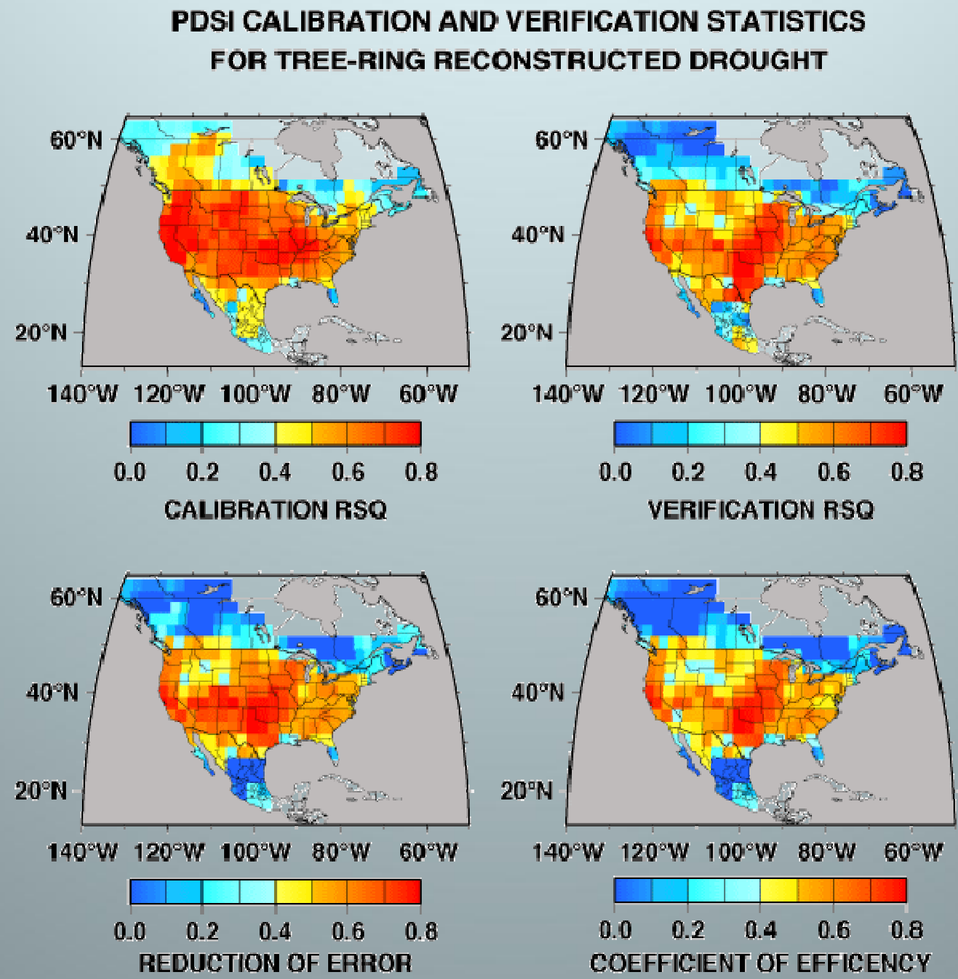

FREQUENCY HISTOGRAM OF STARTING YEARS
OF THE NORTH AMERICAN TREE-RING NETWORK
835 TREE-RING CHRONOLOGIES
COUNT
0
50
100
150
200
250
300
350
0
200
400
600
800
1000
1200
1400
1600
1800
STARTING YEAR



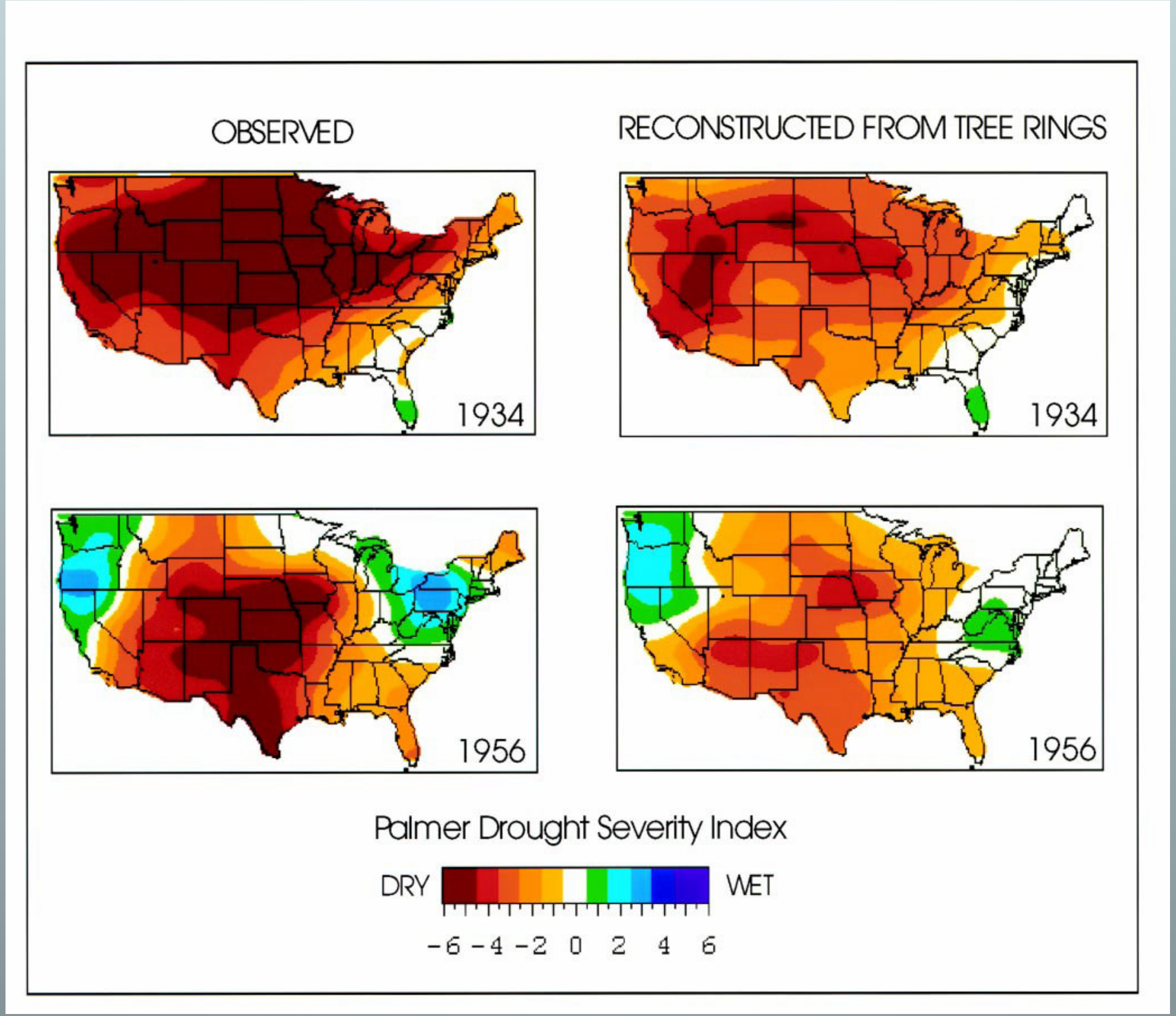
TREE-RING RECONSTRUCTED DROUGHT
GRID-POINTS
60°N
40°N
20°N
140°W
120°W
100°W
80°W
60°W

Calibration and Verification of PDSI

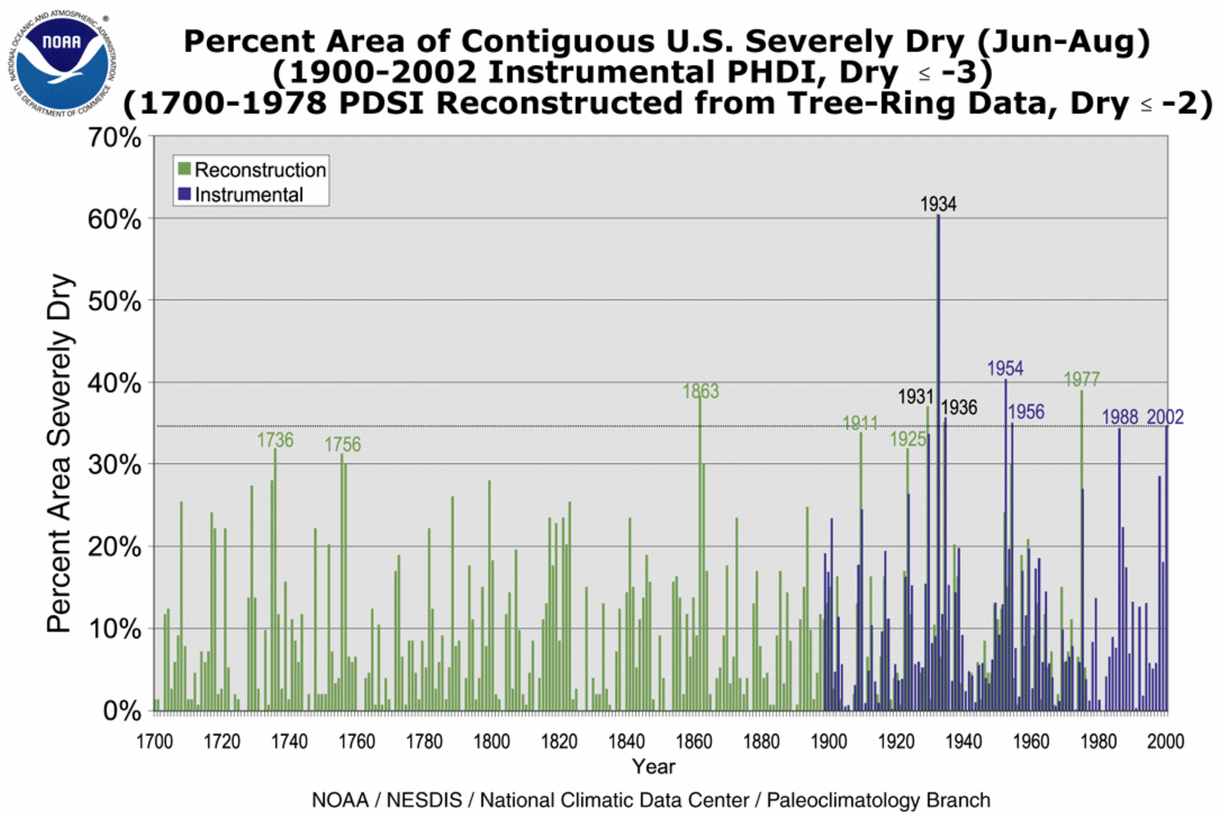
Calibration period:
1928-1978



Verification period:
1900-1927

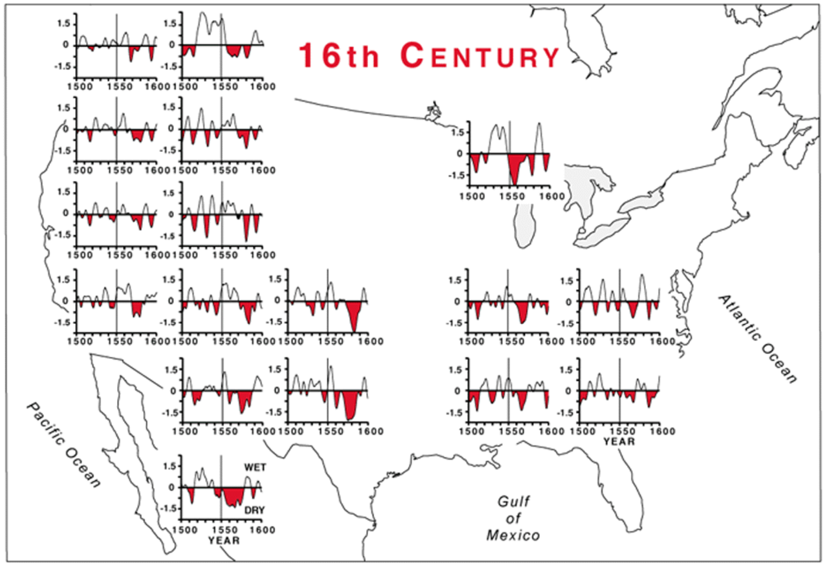

OBSERVED
RECONSTRUCTED FROM TREE RINGS
1934
1934
1956
1956
Palmer Drought Severity Index
DRY
WET
-6 -4 -2 0 2 4 6

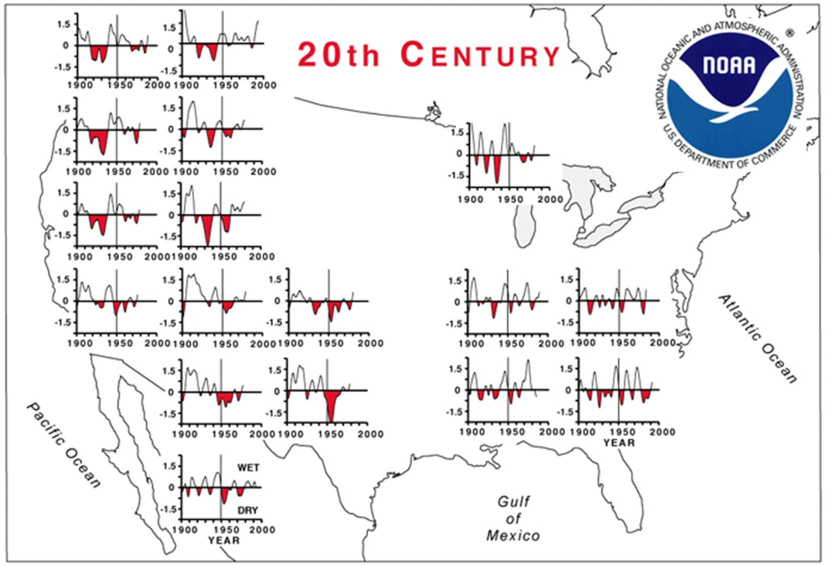
Animation



Percent Area of Contiguous U.S. Severely Dry (Jun-Aug)
(1900-2002 Instrumental PHDI, Dry ≤ -3)
(1700-1978 PDSI Reconstructed from Tree-Ring Data, Dry ≤ -2)
Reconstruction
Instrumental
Percent Area Severely Dry
70%
60%
50%
40%
30%
20%
10%
0%
1736
1756
1863
1911
1925
1931
1934
1936
1954
1956
1977
1988
2002
1700
1720
1740
1760
1780
1800
1820
1840
1860
1880
1900
1920
1940
1960
1980
2000
Year
NOAA / NESDIS / National Climatic Data Center / Paleoclimatology Branch

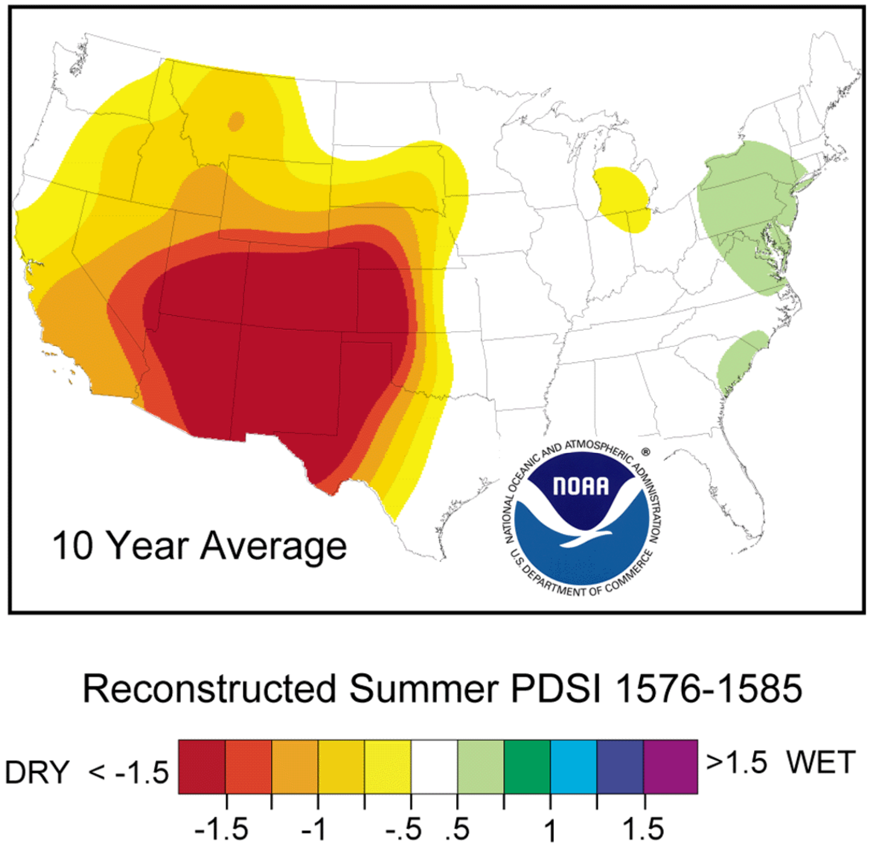
Megadrought





NOAA / NESDIS / National Climatic Data Center, Paleoclimatology Branch

16th Century Megadrought

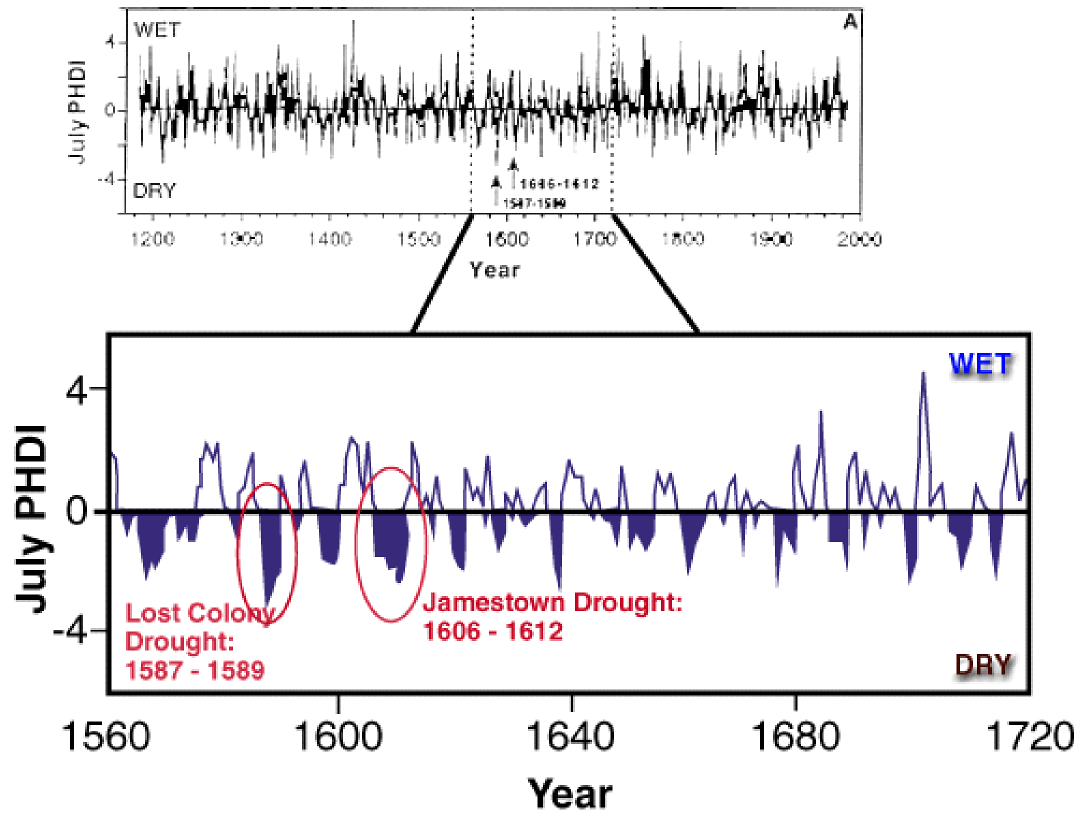


NOAA / NESDIS / National Climatic Data Center, Paleoclimatology Branch

Applications

- Struggles of settlement
- Agricultural production and prices
- Financial stress: tax revenues and regional bank failures
- Demographic patterns: health and migration
- Government responses

Settlement



Tree-ring Reconstruction: July PHDI
Tidewater region of Virginia & N. Carolina
from 1185 to 1984 (top), and
early colonial period 1560 to 1720 (bottom).

Stahle, D.W., M. K. Cleaveland, D. B. Blanton, M. D. Therrell, and D. A. Gay. The lost colony and Jamestown droughts. Science 280 (1998):564-567.

The Future?

- Several droughts of the past 2000 years eclipse those found in the instrument record
- Such severe droughts will likely occur again
- Formulate contingency plans