A Tree-Ring Based Assessment of Synchronous Extreme Streamflow Episodes in the Upper Colorado & Salt-Verde-Tonto River Basins

Key Findings & Implications

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A Collaborative Project between The University of Arizona's Laboratory of Tree-Ring Research & The Salt River Project

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ABSTRACT

Tree-ring reconstructions of total annual (water year) streamflow for gages in the Upper Colorado River Basin and Salt-Verde River Basin were computed and analyzed for the period 1521-1964. These reconstructed flow series were used to identify years of extreme low flow (**L**) and high flow (**H**) discharge in each basin, based on 0.25 and 0.75 quantile thresholds, respectively. Synchronous extreme events in the same direction in both basins (**LL** and **HH** events) were much more frequent than **LH** or **HL** events, which turned out to be extremely rare occurrences. Extreme synchronous low flow (**LL**) and high flow (**HH**) events tended to cluster in time. The longest period of consecutive **LL** years in the record was 3 years. In terms of multi-year extremes, a scenario of 2 extreme years occurring anywhere within a 3-yr or 4-yr moving window was the most common. **The overall conclusion based on the long-term record is that severe droughts and low flow conditions in one basin are unlikely to be offset by abundant streamflow in the other basin.**

For more details, see the project website at:
http://www.ltrr.arizona.edu/srp

KEY FINDINGS & IMPLICATIONS

(1) Gaged vs. Reconstructed Records: Upper Colorado River Basin (UCRB)
& Salt-Verde-Tonto River Basin (SVT)

Findings:

- Mean flow of observed records **higher** than longterm reconstructed means

Implications:

- 20th century has been **wetter in both basins** than in previous centuries.
  (NOTE: recent drought years not included; should lower the observed mean.)

(2) Synchronous Extreme Streamflow Sceanrios:

HH = High flow (**H**) in the UCRB at the same time as high flow (**H**) in the SVT
LL = Low flow (**L**) in the UCRB at the same time as low flow (**L**) in the SVT
HL = High flow (**H**) in the UCRB at the same time as low flow (**L**) in the SVT
LH = Low flow (**L**) in the UCRB at the same time as high flow (**H**) in the SVT

Findings:

- **HH** and **LL** events were much more frequent than **HL** and **LH** events, especially in the long, 444-year reconstructed time series.
- In the reconstructed record: no **HL** events & only 2 **LH** events occurred.
- In the observed record, only 3 **HL** events and no **LH** events occurred.
  *(In order to examine some **LH**-like scenarios in the observed record, the UCRB **L** threshold was relaxed to < 0.50 quantile, yielding **LH** events.)*
- Due in part to the quantile method, the number of **LL** events tends to be counterbalanced by the number of **HH** events, but overall – in both the observed and reconstructed records – **LL events are more frequent occurrences than HH events.**

Implications:

- Working hypothesis that UCRB can serve as a buffer to compensate for extreme low flow in the SVT during drought periods needs to be re-evaluated.
- Assumption that streamflows in the two river systems are relatively independent of each other due to a difference in the climatic regimes needs to be reevaluated.
- Our analysis indicated that:
  -- Flow values in two basins = significantly correlated (444 year record)
  -- **HH** and **LL** events dominated, not **HL** or **LH** scenarios.
- Hence annual streamflow variability in the SVT – especially extreme streamflow – is not independent of annual streamflow variability in the UCRB.
- **Severe drought in one basin will tend to be accompanied by severe drought in the other basin**
- High volume water supply of the large UCRB may allow continued buffering during climate stress; but demand on this supply also increasing due to non-climatic factors

(3) Persistence of Extreme Streamflow Episodes

Findings:

- strong tendency for **extreme years to occur in sequences or clusters**
- strong evidence of a linkage in **multi-year drought occurrence in the two basins**

Implications:

- If # of wet extreme years = # of dry extreme years, could "cancel each other" on a year-to-year basis ➔ little long-term stress on water supply operations.
- Because of clustering tendency, more probable that episodes of sustained drought or sustained high flow will persist ➔ *more* of a burden on water systems management
- **Reservoir storage can buffer water supplies but supplies will be increasingly strained as droughts extend over multi-year periods**

(4) Longterm (multi-century) Variability

Findings:

- Some past periods / centuries have experienced more variability in extremes (**HH** and **LL**) than others
- 20th and 21st century have fairly good representation of extremes when compared to longterm record; but higher magnitude flows and higher #'s of extremes do occur in reconstructed record
- Low-frequency variation apparent in longterm record

Implications:

- Observed record a fairly good indicator of past extremes, but does not reflect the highest or lowest flows possible, nor the longest persistence of extremes
- Understanding climatic drivers for low-frequency variations key to better longterm management of supply; but at present ultimate causes are unknown

(5) Circulation Patterns Leading to LL, HH, LH and HL Scenarios

Findings:

- Characteristic circulation pattern for **LL** events is higher-than-normal upper level pressure over the west in early winter (Oct -Dec) & over the North Pacific ocean storm track region in mid- to late winter (Jan - Mar).
- Inverse of this pattern leads to **HH** events.
- **LH** and **HL** scenarios arise when the Pacific storm track appears to shift to an anomalous poleward (**HL**) or equatorward (**LH**) location

Implications:

- Persistent circulation anomalies are important for development of extreme episodes
- Development of circulation patterns may help in assessment of impending scenarios

(6) Driving Mechanisms of Longterm Variability

Findings:

- Preliminary examination of El Niño, La Niña influences and ocean indices such as the Pacific Decadal Oscillation (PDO), and the Atlantic Multidecadal Oscillation (AMO) suggest linkage to some – but not all **LL** years in the observed record

Implications:

- +AMO / -PDO sea-surface temperature anomaly "driver" a possible influence on synchronous episodes, but more analysis needed
-

(7) Severity of Recent Drought on Salt River in a Multicentury Context

Findings:

- 1-year Salt R flows of the basin decreased beginning in water-year 1994 and culminated in single-year flows for 2000 & 2002 lower than any previously experienced in the observed record
- As a 5-year running mean, the recent drought is about as severe as the lowest-flow period in the 1950s.
- As 11-year running mean, also about as severe as the 1950s --suggests that the period commencing with the decline in water year 1994 and continuing through water year 2004 ranks with the driest conditions in the entire gaged record.
- As 15-year running mean, recent drought no longer ranks among the most severe (due to wet sequence of years in the early 1990s)
- Up to an averaging period of 11 years, the recent drought is at least comparable in severity to any earlier drought in the gaged record.
- Tree-ring reconstruction for SVT ends in 1988, and so does not cover the recent drought, but because the 1950s drought was characterized by flow departure of roughly the same magnitude as the recent drought, we can use the lowest reconstructed flows of the 1950s to indirectly evaluate the relative severity of the recent drought in the context of the reconstruction to A.D. 1199.
- A plot of 11-year running means of the SVT reconstruction with the baseline marked as the low point in the 1950s suggests that the current drought was exceeded in severity several times in the past 800 years
- **Eight distinct periods before the start of the gaged record show lower 11-year mean flow than the lowest reconstructed value of the 1950s.** The **most severe of the tree-ring droughts** was in the **late 1500s**, during the well-documented "mega-drought" of North America, when 11-year average flow is reconstructed about 100 cfs below the lowest flows of the 1950s.

Implications:

- **BOTTOM LINE: The recent drought, while severe, does not appear to be unprecedented when viewed in a multi-century context.**

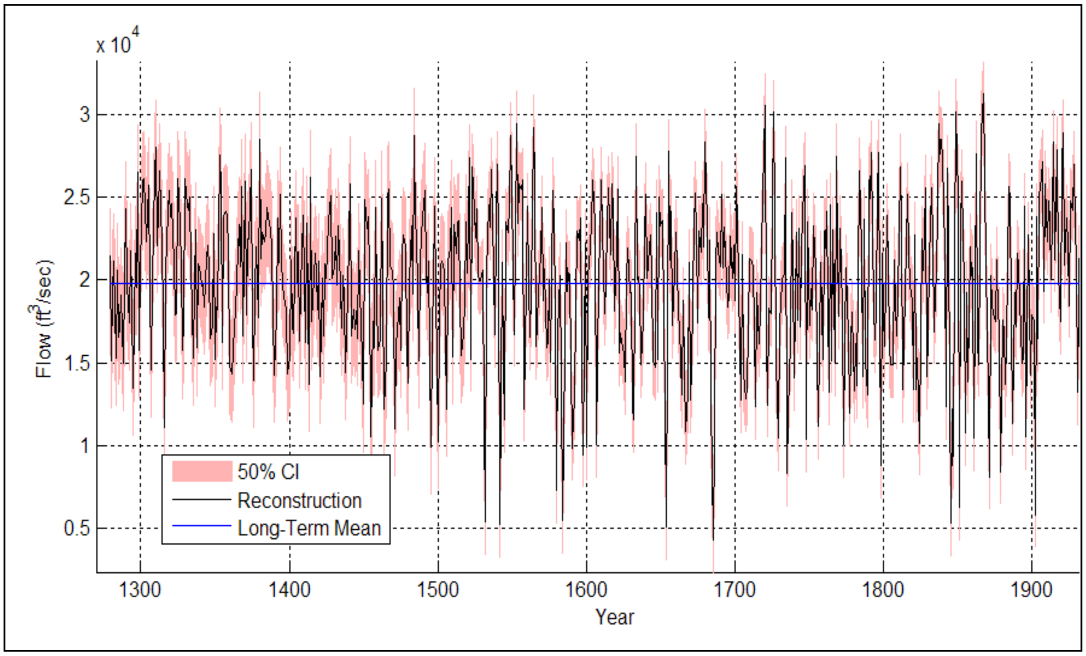


Figure 7a -- Reconstructed annual water year flows, Colorado River at Lees Ferry.

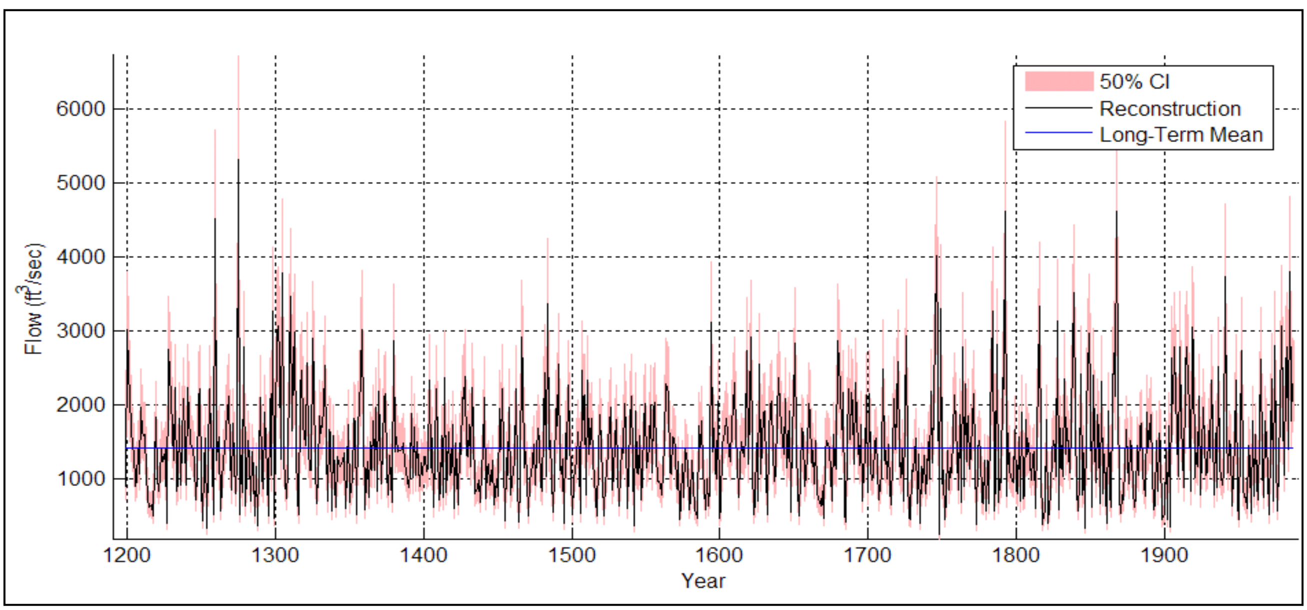


Figure 7b -- Reconstructed annual flows, Salt+Verde+Tonto Rivers, Arizona

Table 2 – Thresholds for determining low (L) & high (H) flow extremes in each basin.

THRESHOLDS OF OBSERVED & RECONSTRUCTED FLOW FOR HH / LL ANALYSIS

BASIN		QUANTILE	% MEAN	CFS	Thousands of Acre-Feet
UCRB @ Lees Ferry	L	0.25	77.4 83.3	15,910 16,326	11,526 11,827
	H	0.75	119.9 119.6	24,649 23,422	17,857 16,968
S + V+ T (Salt + Verde + Tonto)	L	0.25	49.5 63.1	835 887	605 642
	H	0.75	123.1 126.1	2,077 1,772	1,505 1,283

	Observed	Reconstructed
Base period for quantiles: water years	1914-2001	1521-1964
Means: A. Colorado R at Lees Ferry:	20,564 cfs	19,589 cfs
B. Salt, Verde and Tonto:	1,687 cfs	1,405 cfs

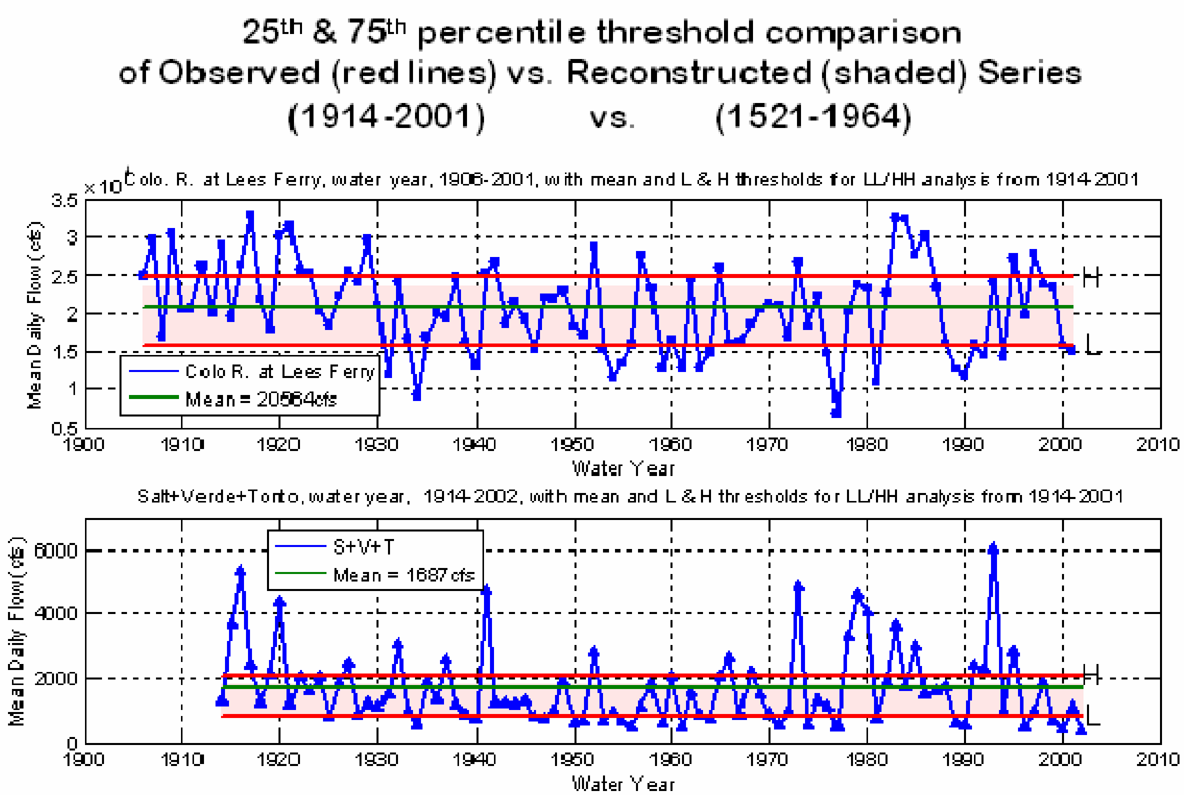


Figure 8 – Comparison plot of quantile thresholds for observed & reconstructed time series

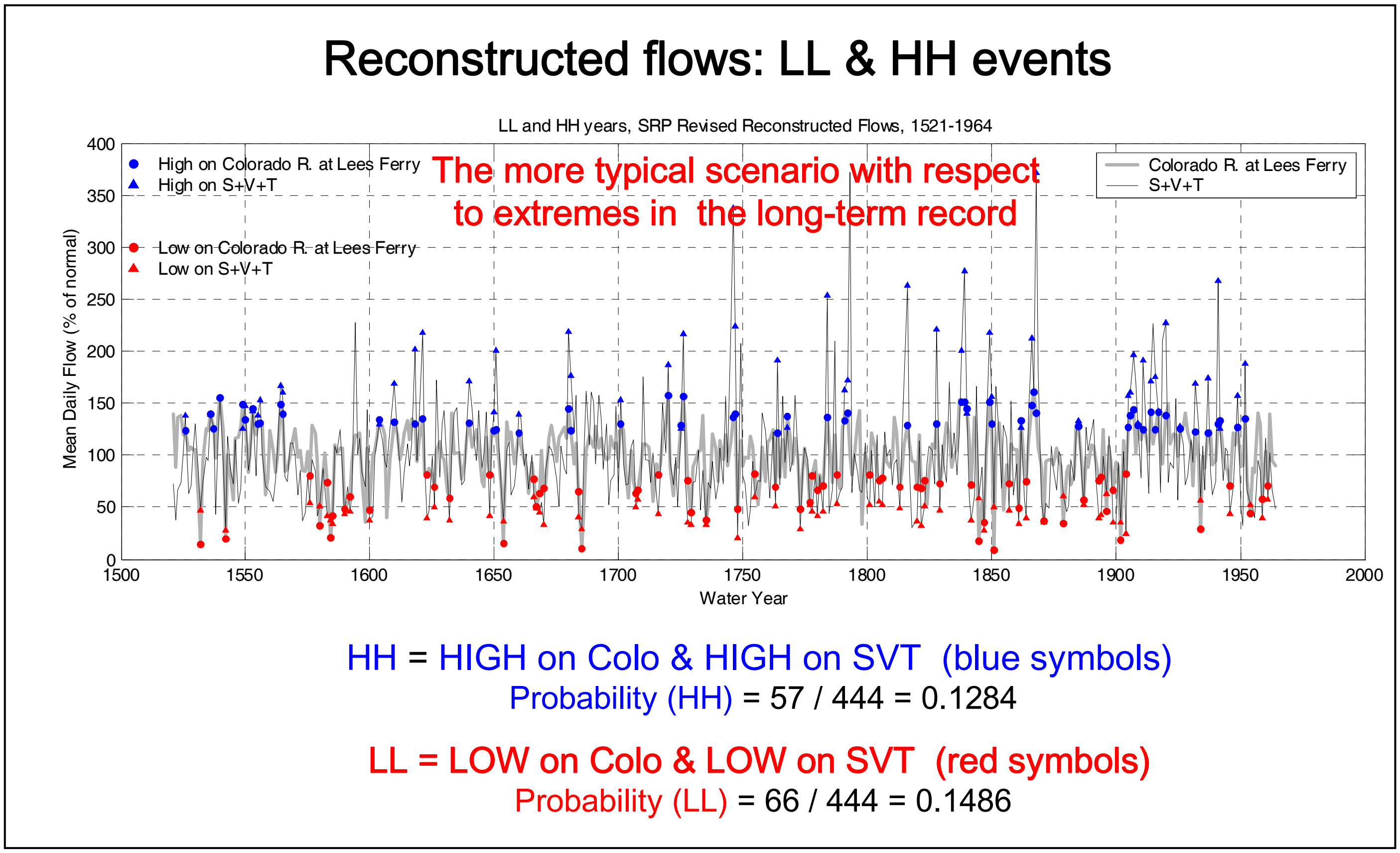


Figure 11 – **HH** and **LL** water years based on reconstructed-record quantiles from 1521 - 1964

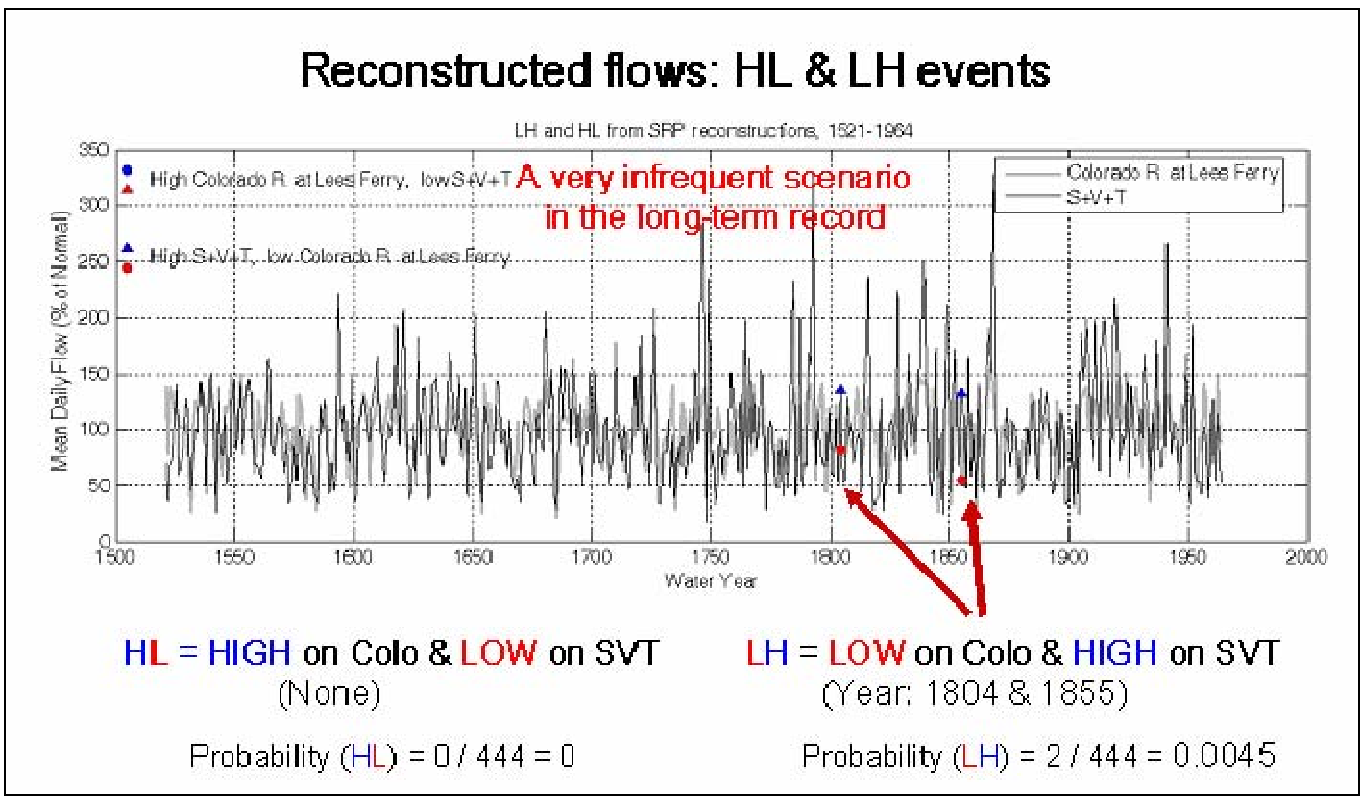
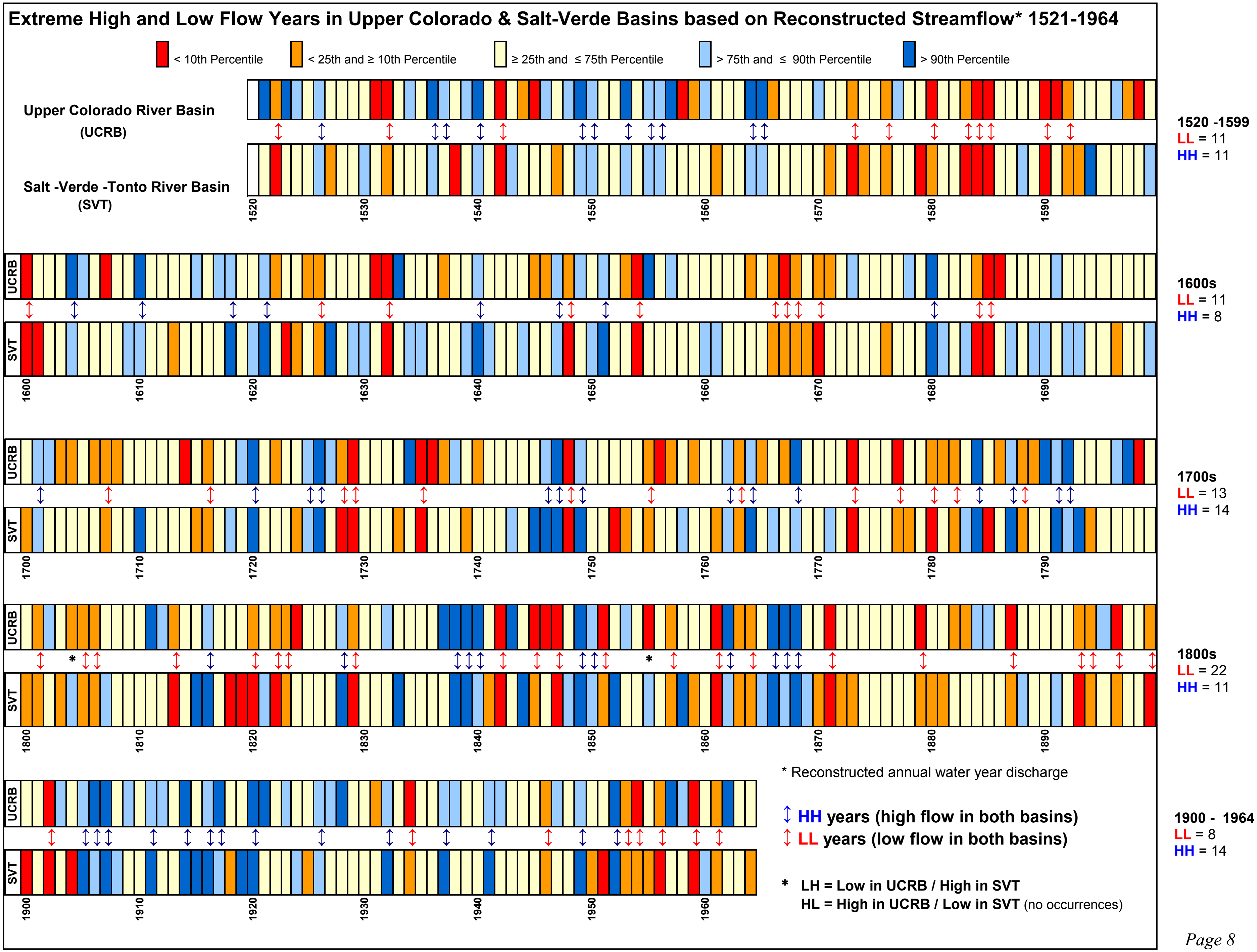
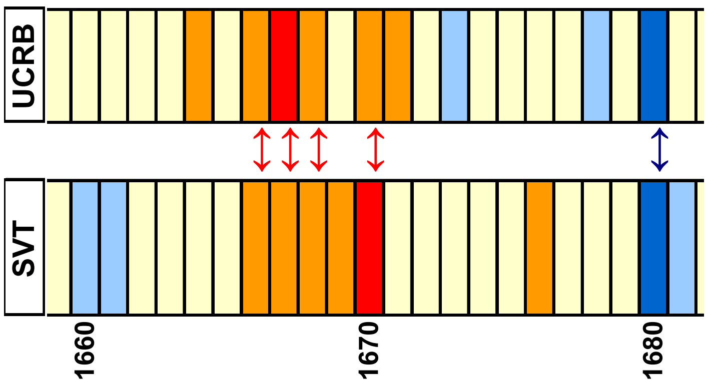


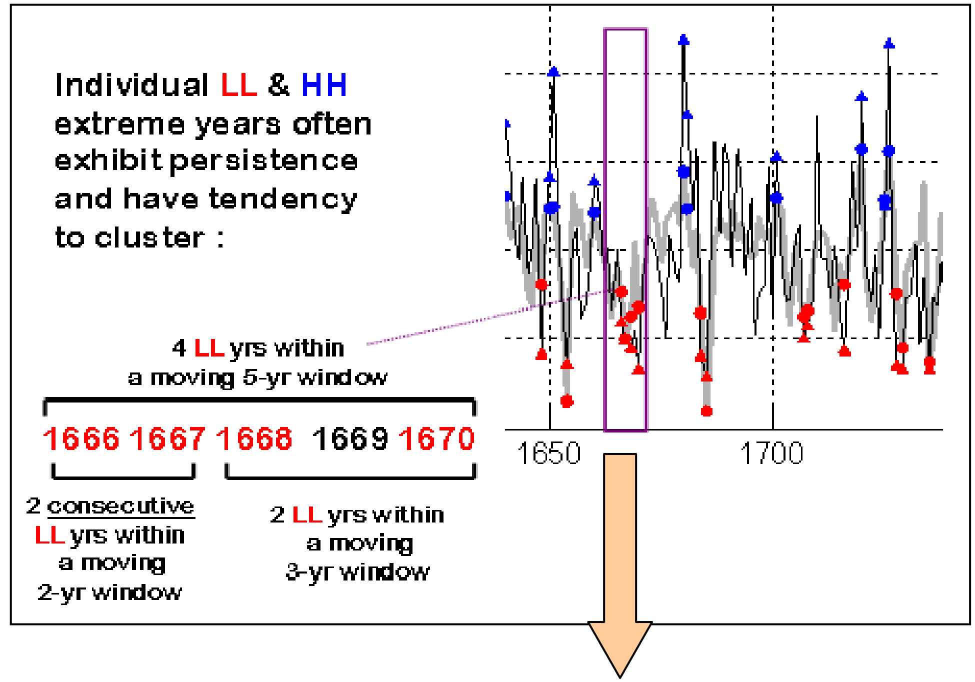
Figure 12 – **HL** and **LH** water years based on reconstructed-record quantiles from 1521 - 1964

Figure 15 – **LL** and **HH** water years with quantile time series



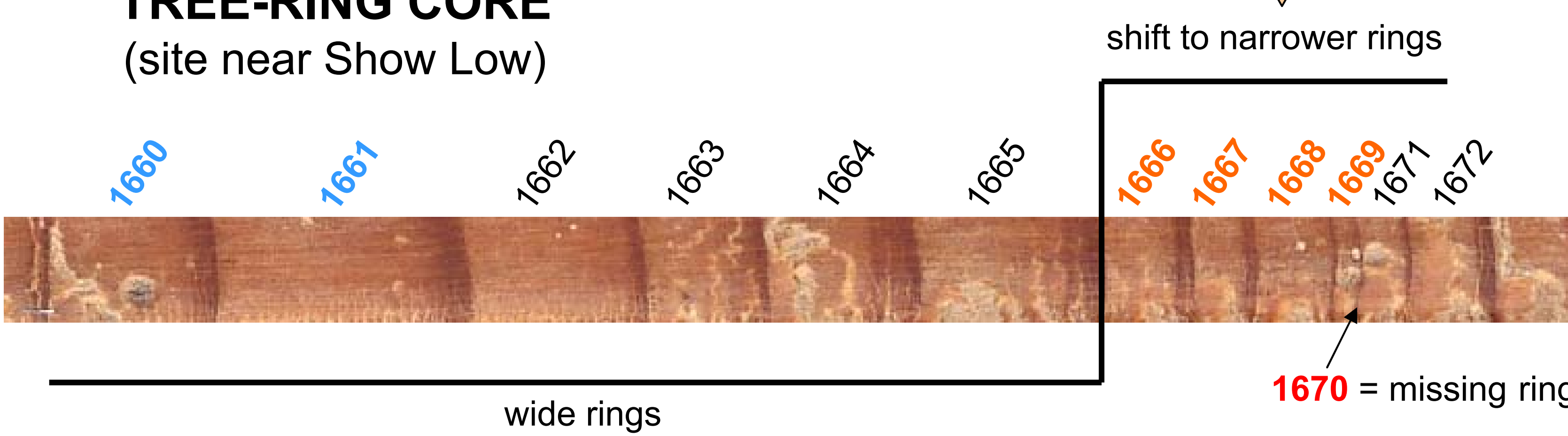
Extreme High & Low Flow Years



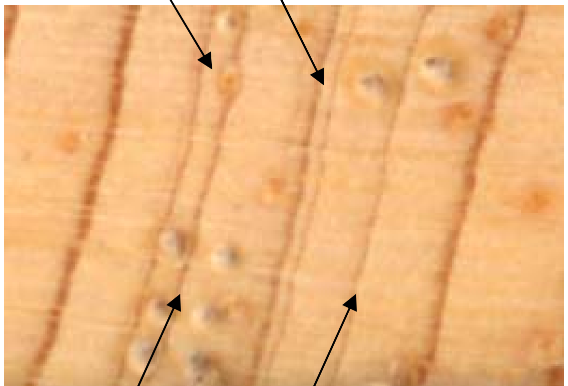


SALT RIVER BASIN TREE-RING CORE

(site near Show Low)

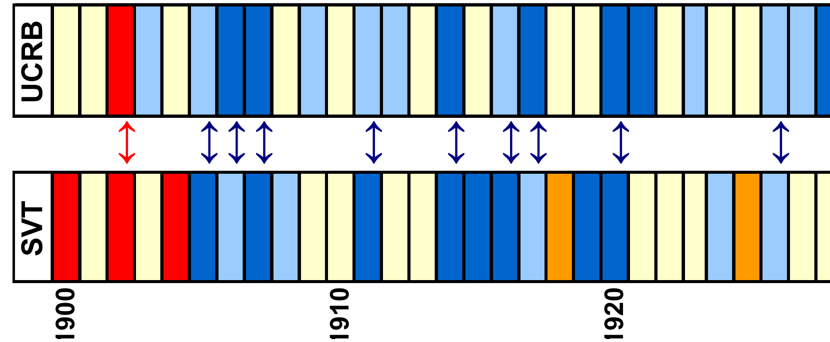


1899 &1902 = narrow rings (dry)



1900 & 1904 = missing rings (dry)

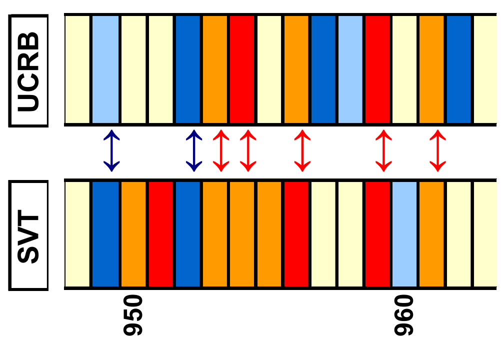
Extreme High & Low Flow Years



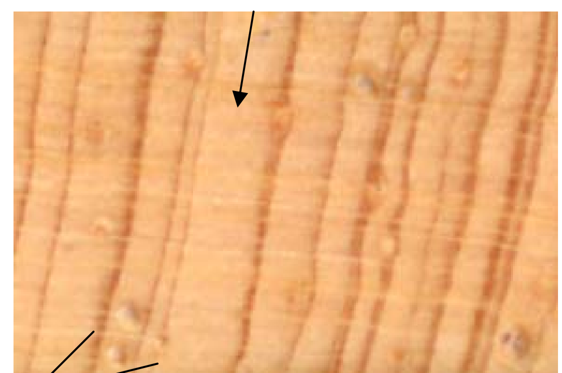
SALT RIVER BASIN TREE-RING CORE

(site near Show Low)

1905 -1908 & 1914 – 1920 (very wet)



1952 (wet)



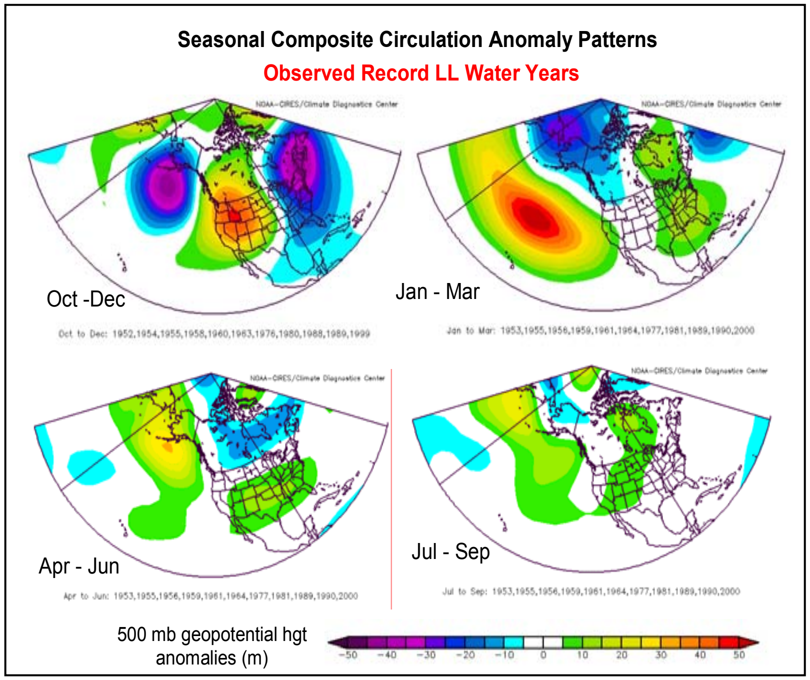
1950 &1951

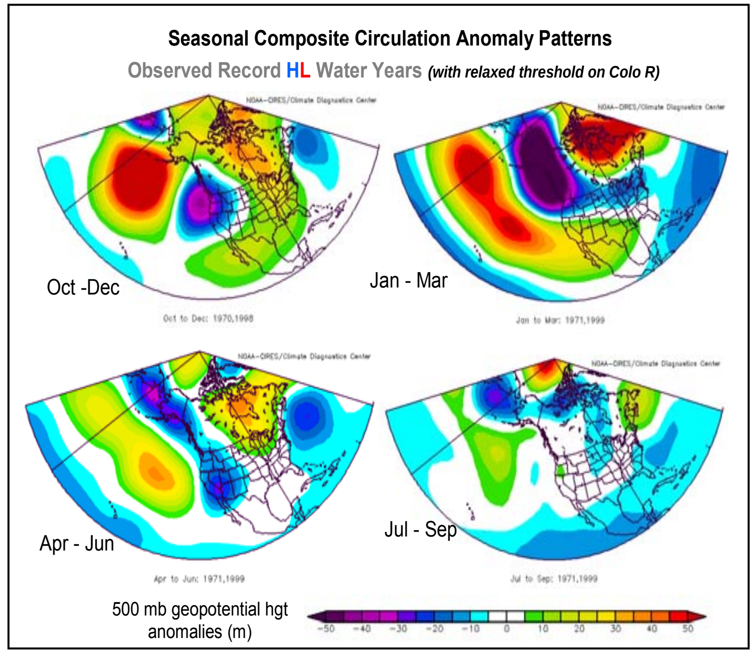
1953 -1956 (dry)

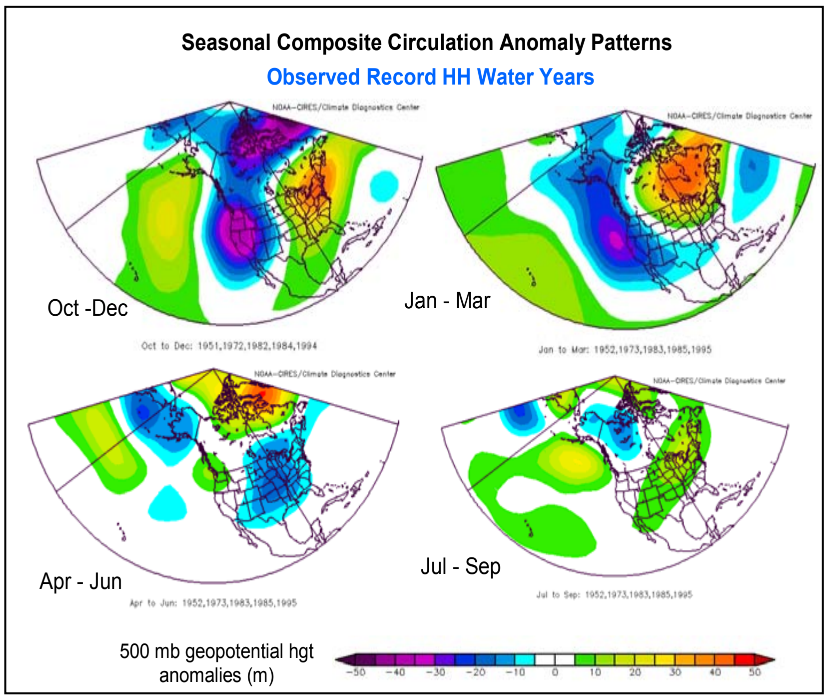
Table 3 -- Probability Counts of LL & HH Event Scenarios

Most probable	**Over the period 1521-1964**	**LL** **# events/ # possible (probability)**	**HH** **# events / # possible (probability**
***	Individual 1-yr events	66 / 444 (0.149)	57 / 444 (0.128)
	Consecutive Sequences		
*	2 consecutive years *(within a moving 2-yr window)*	10 / 443 (0.023)	14 / 443 (0.032)
	3 consecutive years *(within a moving 3-yr window)*	1 / 442 (0.002)	3 / 442 (0.007)
	Clustered Sequences		
**	2yrs *(within a moving 3-yr window)*	22 / 442 (0.050)	29 / 442 (0.066)
***	2 yrs *(within a moving 4-yr window)*	45 / 441 (0.102)	47 / 441 (0.107)
	3 yrs *(within a moving 4-yr window)*	5 / 441 (0.011)	9 / 441 (0.020)
*	3 yrs *(within a moving 5-yr window)*	13 / 440 (0.030)	16 / 440 (0.036)
	4 yrs *(within a moving 5-yr window)*	1 / 440 (0.002)	0 / 440
	4 yrs *(within a moving 6-yr window)*	1 / 439 (0.002)	0 / 439
	5 yrs *(within a moving 6-yr window)*	0 / 439	0 / 439

*** = probability > 10% ** = probability > 5% * = probability > 2%







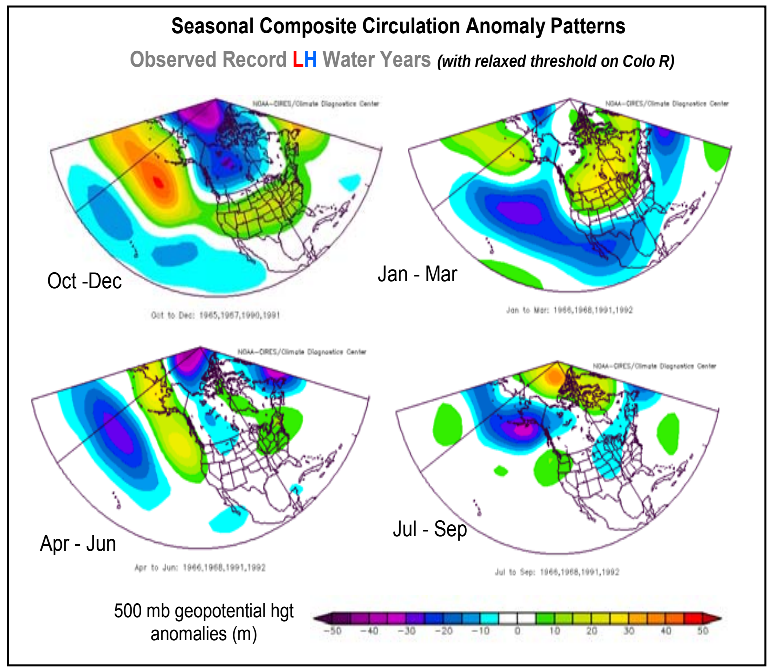


Figure 21a – Composite circulation anomaly patterns for LL and HH years

Figure 21b – Composite circulation anomaly patterns for HL

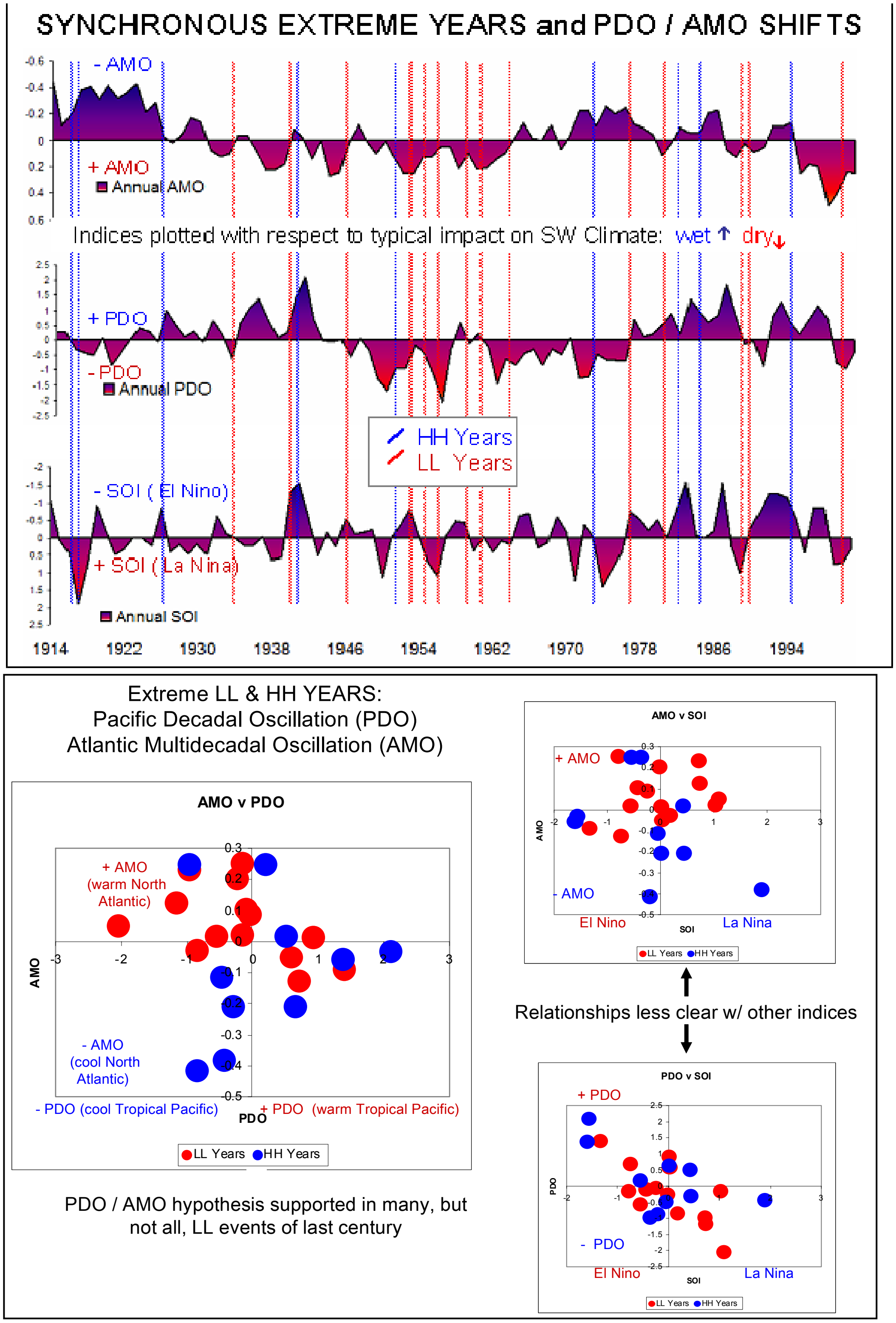
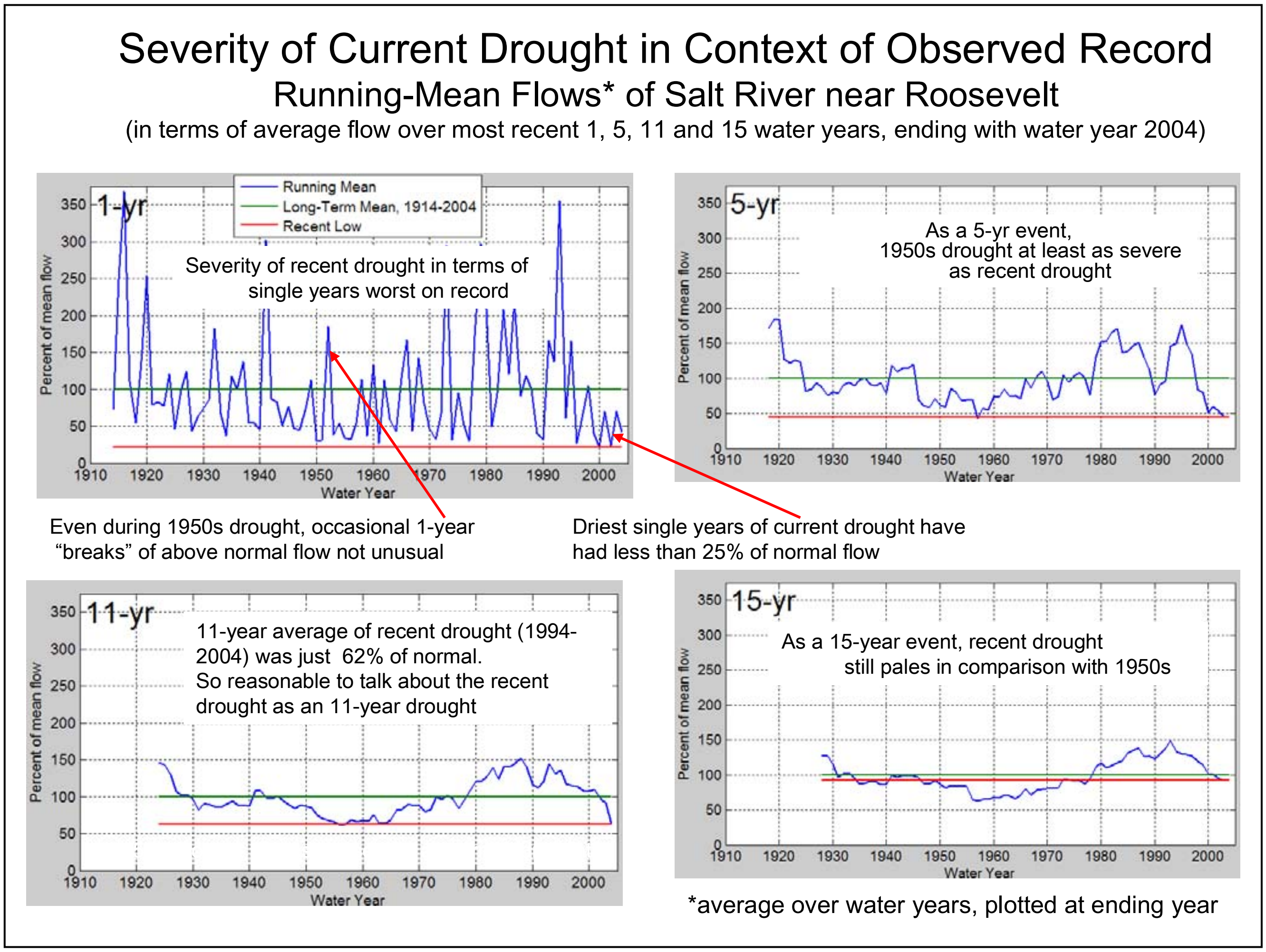


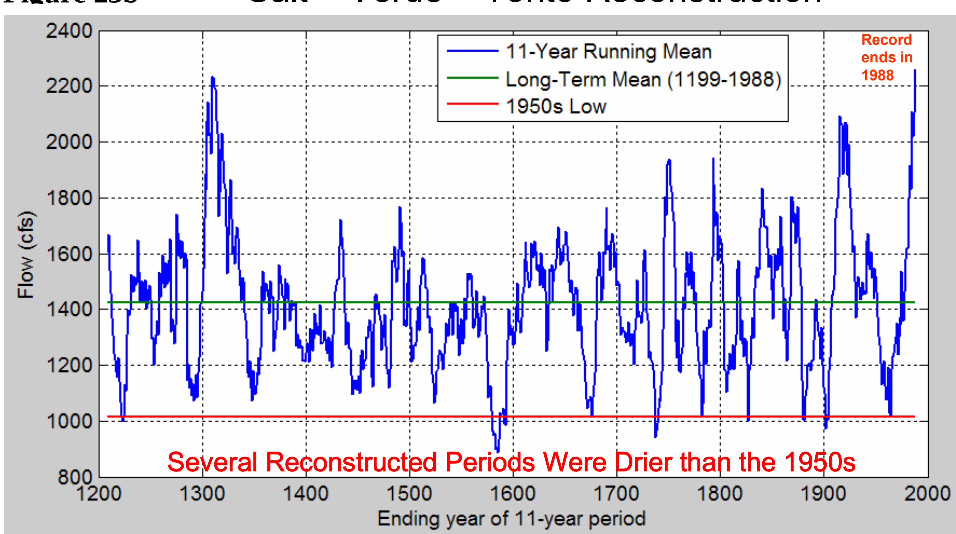
Figure 22 – Extreme years and PDO / AMO / ENSO

Figure 23a – The recent drought in context



Severity of Current Drought in Context of Reconstructed Record:

Figure 23b Salt + Verde + Tonto Reconstruction



-- Current drought was about as severe as 1950s in terms of flows averaged over 11 years
-- 8 other droughts were as severe, according the tree-ring record
-- Late 1500s megadrought was much more severe