Climate Change & Southwest Riparian Areas:

How "Connecting the Dots" between the Past, the Present, and Processes can help us address concerns of climate change & variability in SW Riparian Areas

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Laboratory of Tree-Ring Research

University of Arizona

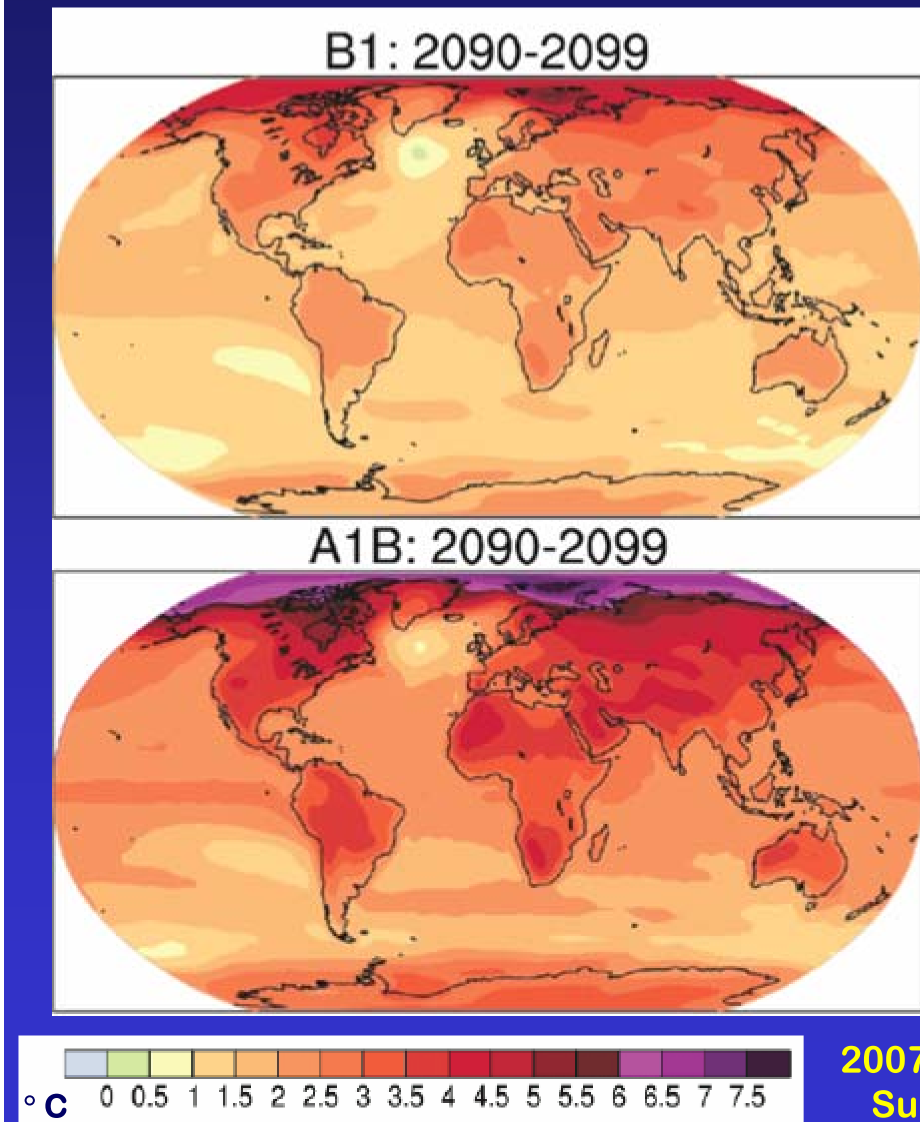
Climate and Riparian Areas Workshop
Connecting the Dots – Climate Change/Variability and Ecosystem Impacts in Southwestern Riparian Areas – April 11, 2007

The Laboratory of Tree-Ring Research

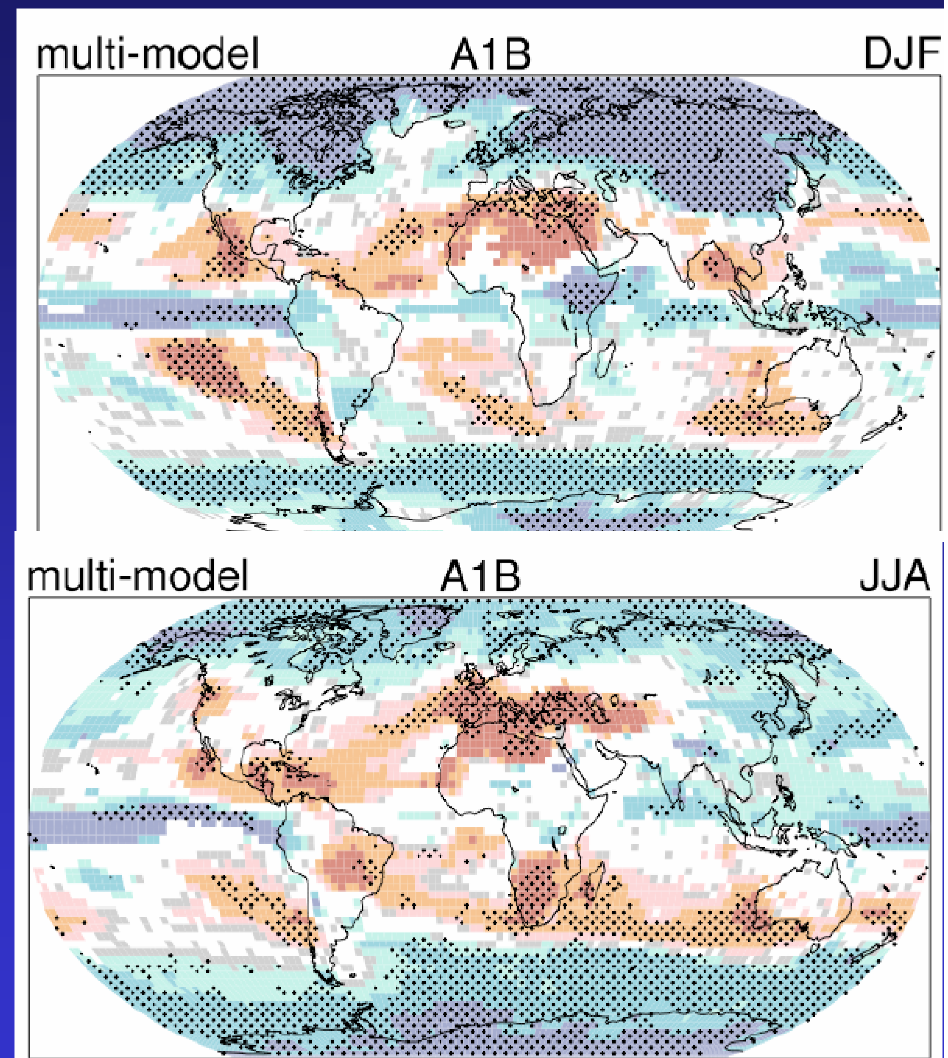
CLIMAS Climate Assessment for the Southwest

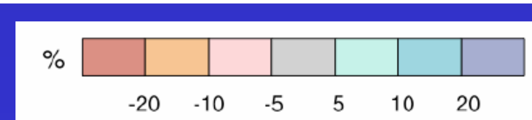
Some Global Temperature & Precipitation Projections:

Projections of Surface Temperatures



Projected Patterns of Precipitation Changes





2007 IPCC WG I Summary for Policymakers


Arizona Daily Star
www.dailystar.com www.azstarnet.com
Published: 04.06.2007
Study predicts dust-bowl Southwes
The New York Times
nytimes.com
March 27, 2007
Heat Invades Cool Heights Over Arizona Desert
Arizona Daily Star
www.dailystar.com www.azstarnet.com
Published: 04.09.2007
SE Ariz. desert 1 of 10 'treasures' at warming risk
Southwest HYDROLOGY
The Resource for Semi-Arid Hydrology
January/February 2007
Volume 6/Number 1
Inconvenient Hydrology?

Sciencexpress Report

Model Projections of an Imminent Transition to a More Arid Climate in Southwestern North America

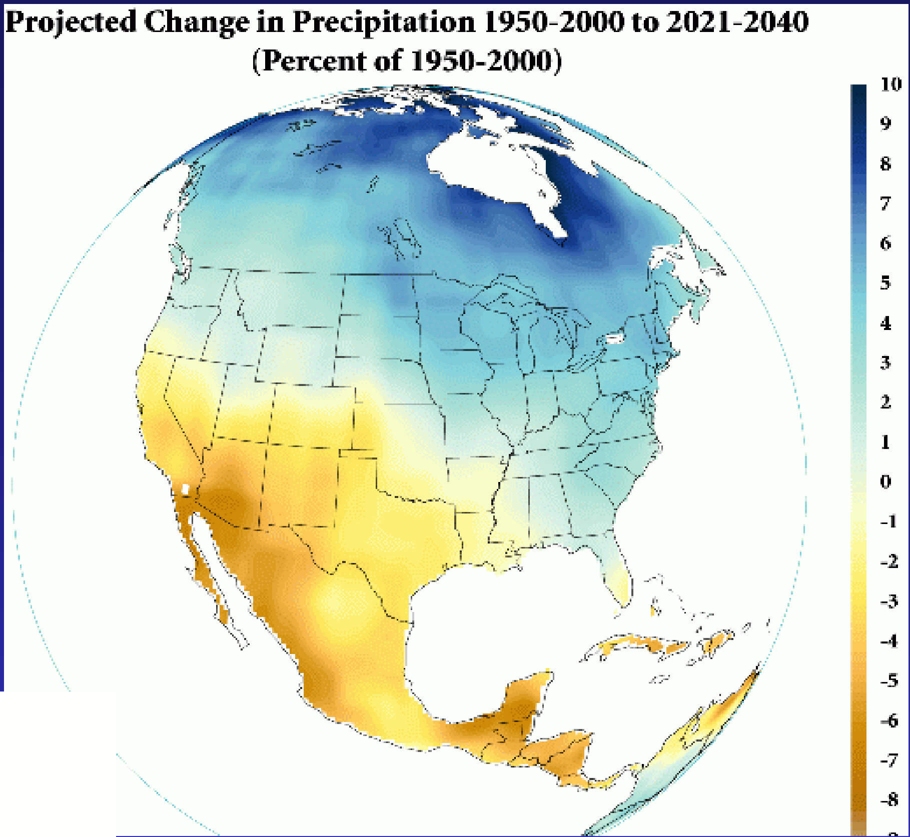
Richard Seager et al., April 2007 *Science*

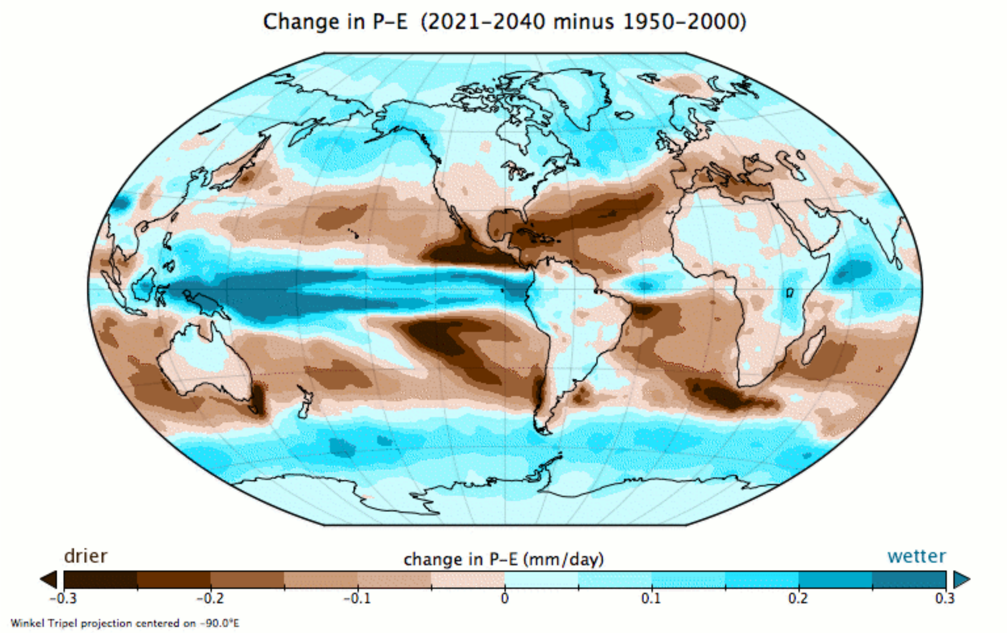
- 19 different climate modeling groups
- Widespread agreement that Southwestern North America [is] on a trajectory to a climate even more arid than now.
- Becomes marked early in the current century.

" In the Southwest the levels of aridity seen in the 1950s multiyear drought, or the 1930s Dust Bowl, become the new climatology by mid-century: a perpetual drought."

Seager et al. 2007:

- Hadley Cell expands poleward
- Descending air suppresses precipitation by drying the lower atmosphere
- subtropical dry zones expand

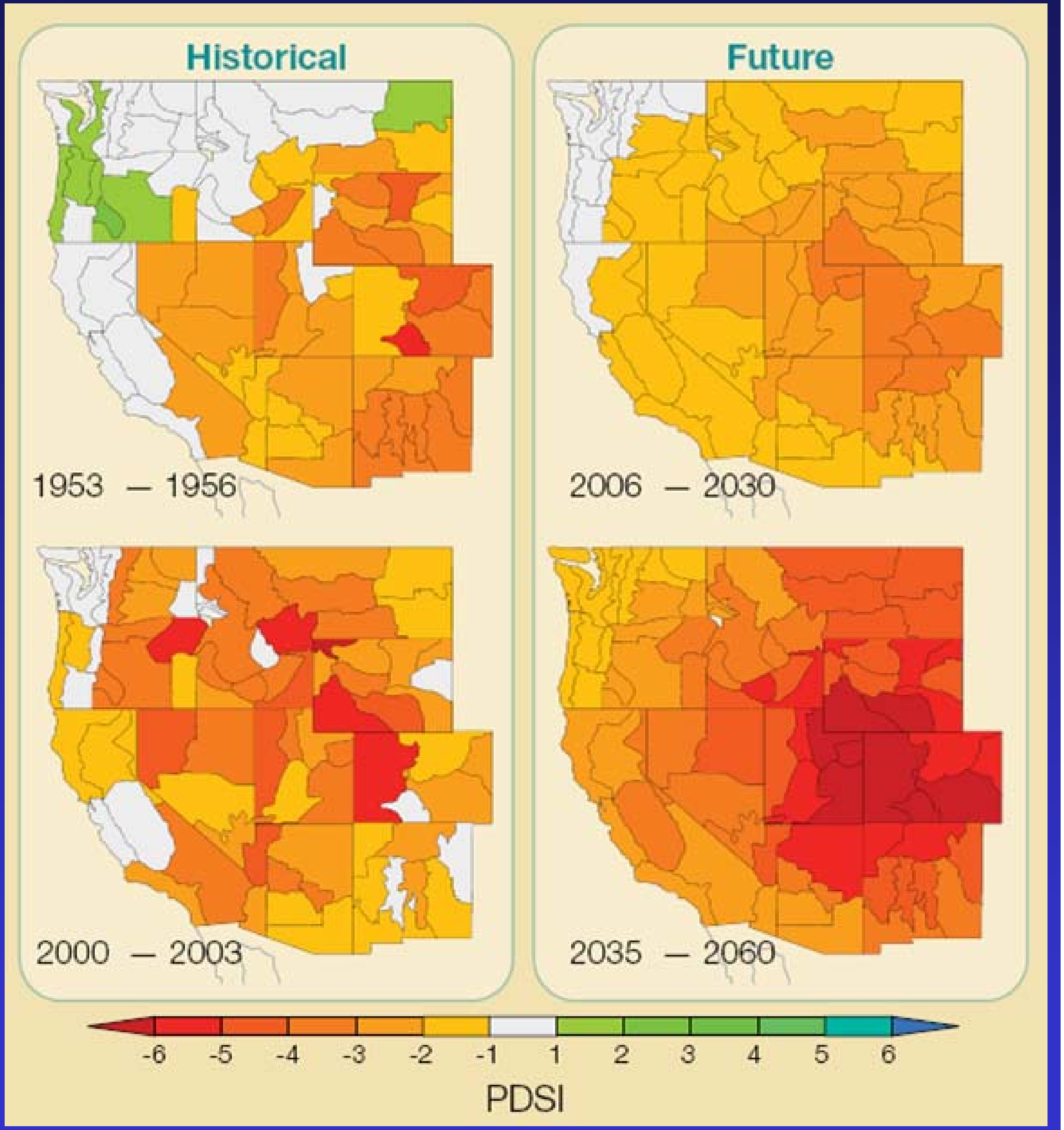




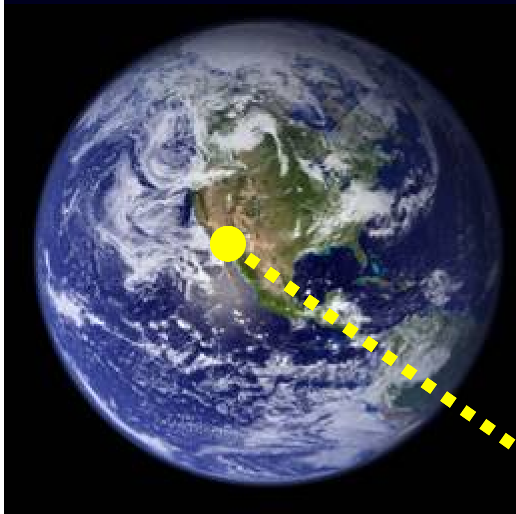
- Rain-bearing mid-latitude storm tracks shift poleward
- Both changes cause the poleward flanks of the subtropics to dry.

http://www.ldeo.columbia.edu/res/div/ocp/drought/science.shtml

Typical scale of future regional projections: based on coupled ocean-atmosphere-land models



Source:
Hoerling & Eischeid 2007
in Southwest Hydrology



Key Question:

How do we transfer the growing body of knowledge and assertions about global climate change and variability to individual Southwestern watersheds and their riparian areas?

Issues of spatial and temporal scale are of key importance in understanding the processes involved in the delivery of precipitation and the resulting riverine response in individual watersheds.

This presentation argues:

. . . that attention to some very basic hydrologic and geographic elements at the local and regional watershed scale

-- such as basin size, watershed boundaries, storm type seasonality, atmospheric circulation patterns, and geographic setting

. . . can provide a basis for a cross-scale approach to linking GLOBAL climate variability with LOCAL hydrologic variations in riparian areas . . .

. . . . including EXTREME EVENTS
in the “tails” of streamflow
probability distributions,
such as floods and droughts.

In other words we will . . . .

. . . let the rivers “speak for themselves” about how they respond to climate .

A systematic compilation of watershed-specific information about spatially and temporally varying hydroclimatic extremes is proposed as a starting place for making operationally useful decisions about prospective climatic changes.

Climate Change & Southwest Riparian Areas "Connecting the Dots"

I. Connecting across Time

II. Connecting across Scales

III. Connecting between streamflow, storms, circulation patterns, & climate variations

IV. Concluding Remarks

Climate Change &
Southwest Riparian Areas
"Connecting the Dots"

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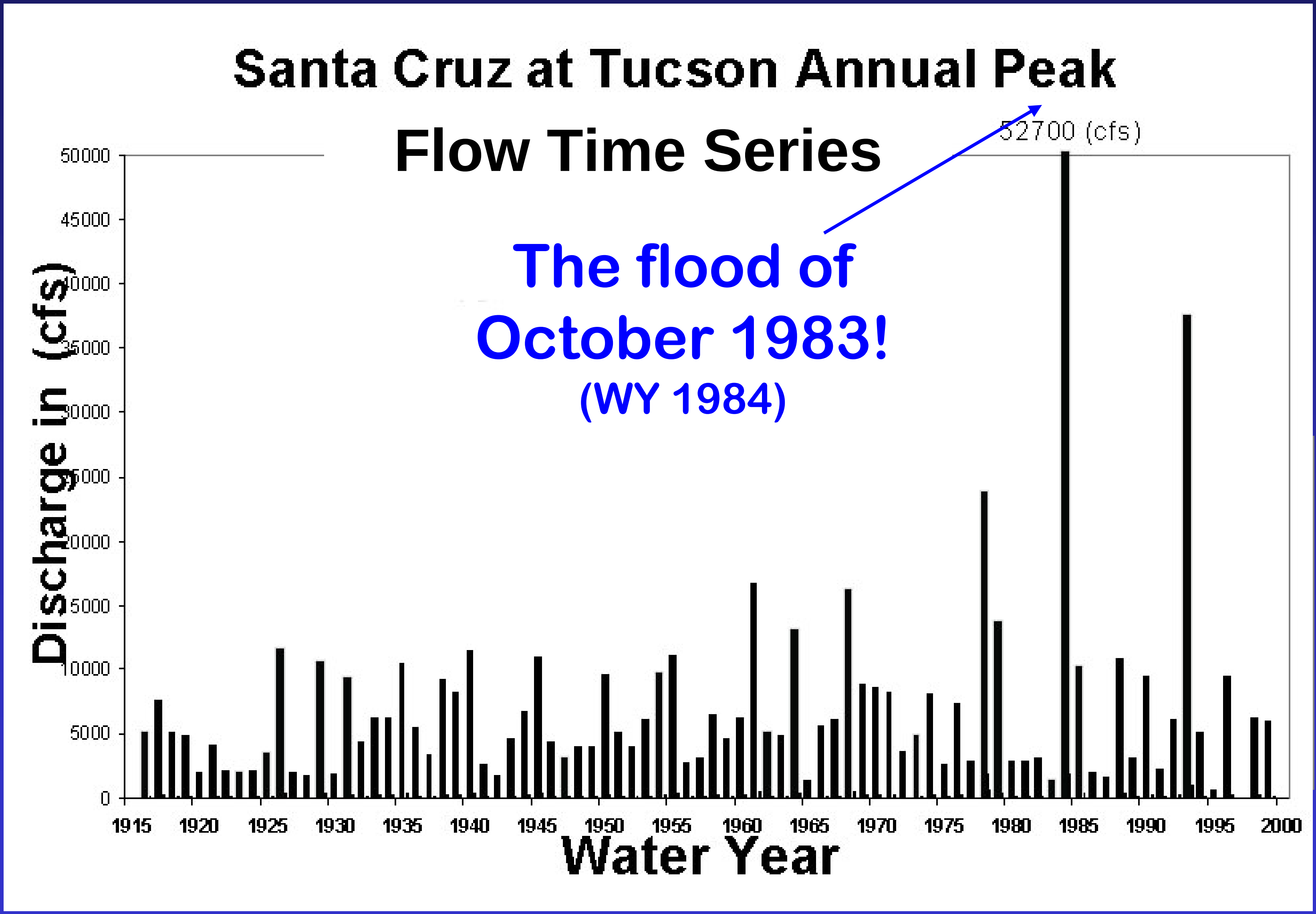
Rivers have histories . . . . peak flows:

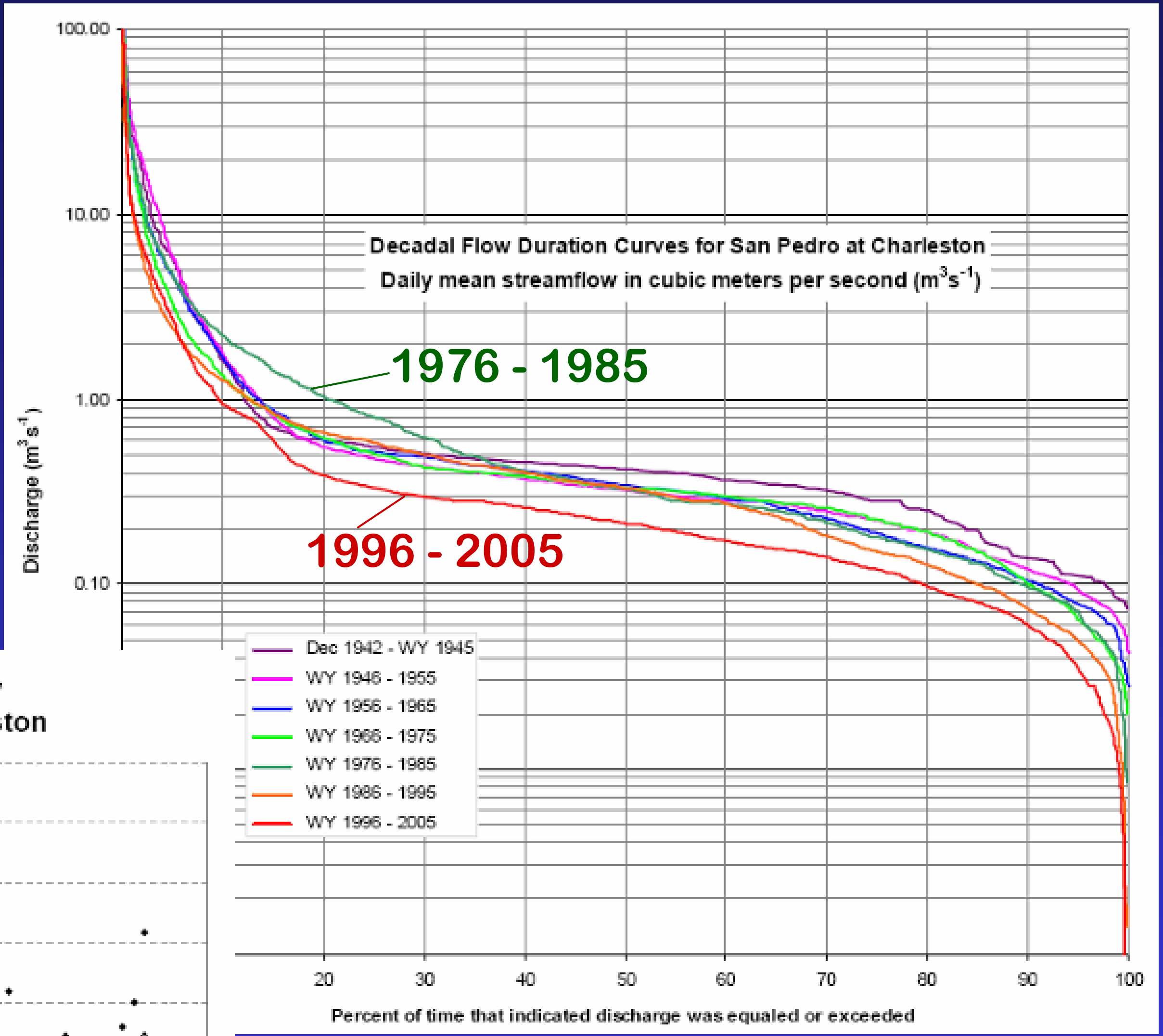


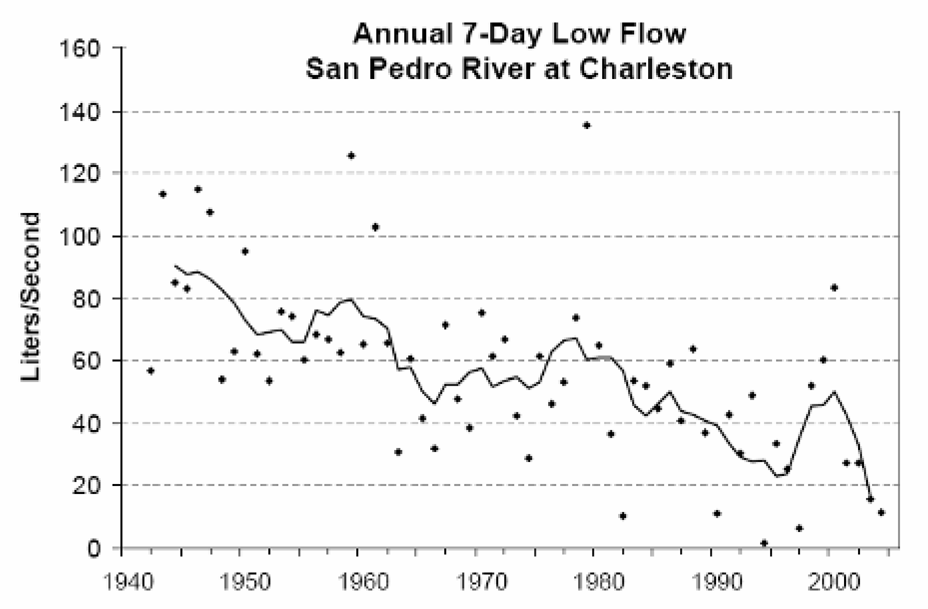
Rivers have histories . . . . mean and low flows

San Pedro River

Decadal differences in daily mean streamflow ➔

From: MacNish et al. "Hydrology of the San Pedro Basin" in Stromberg & Tellman, (forthcoming)





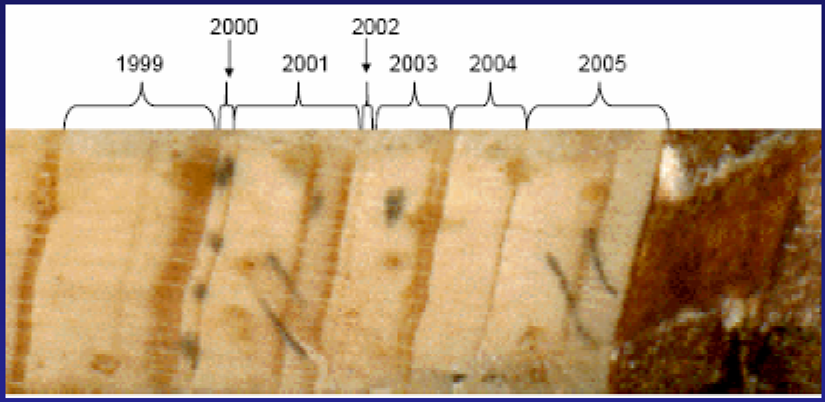
🡐 Time series of 7-Day Low Flow from 1940 - 2002

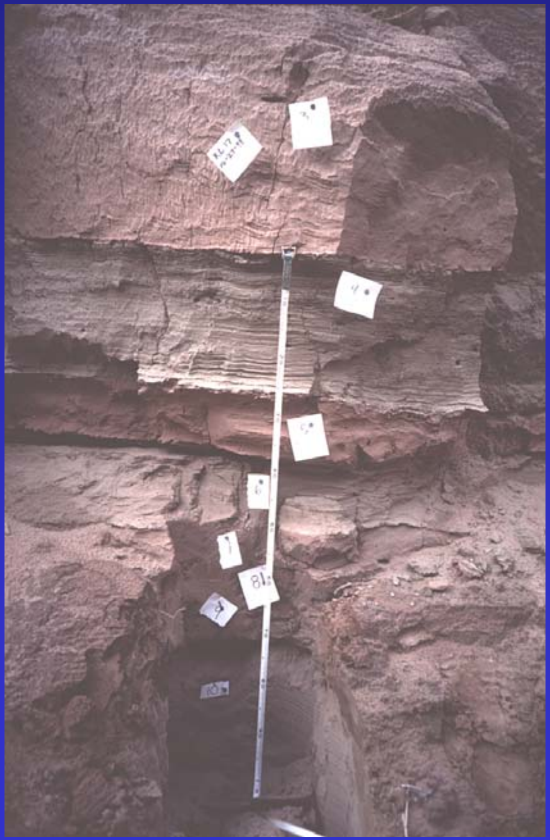
As long a record as possible is the ideal . . . especially to understand and evaluate the extremes of floods and droughts:

By definition extreme events are rare, hence gaged streamflow records capture only a recent sample of the full range of extremes that have been experienced by a given watershed.

Information extracted from . . .

TREE RINGS



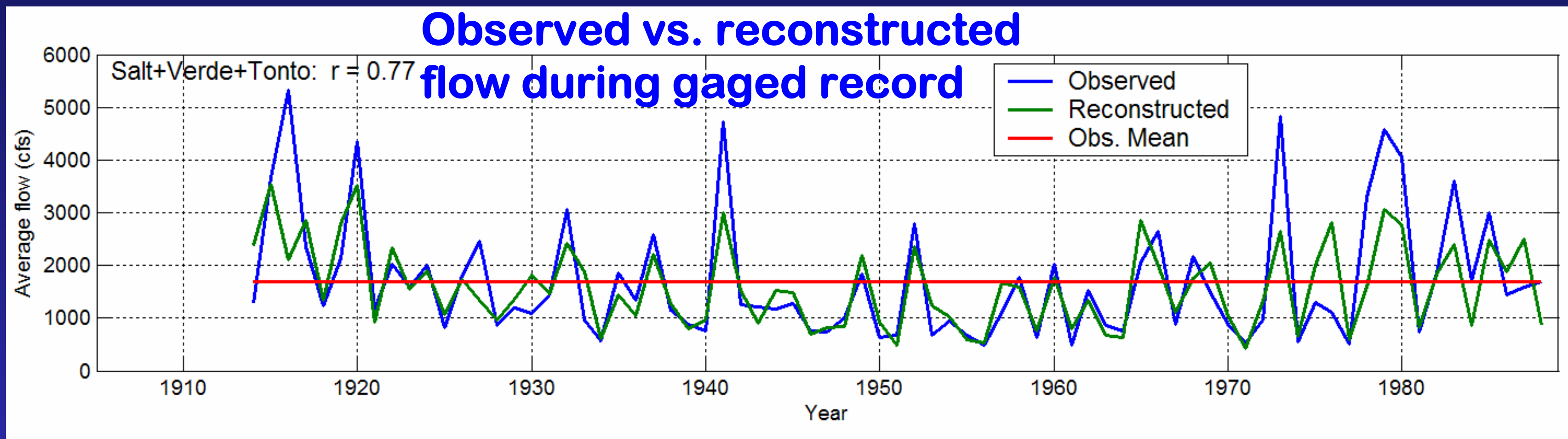


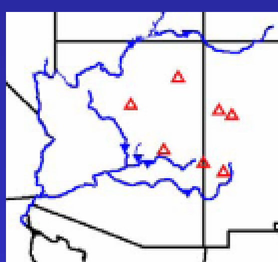
&

STRATIGRAPHIC
PALEO - STAGE INDICATORS

can augment the gauged record of extreme events in some Arizona watersheds.

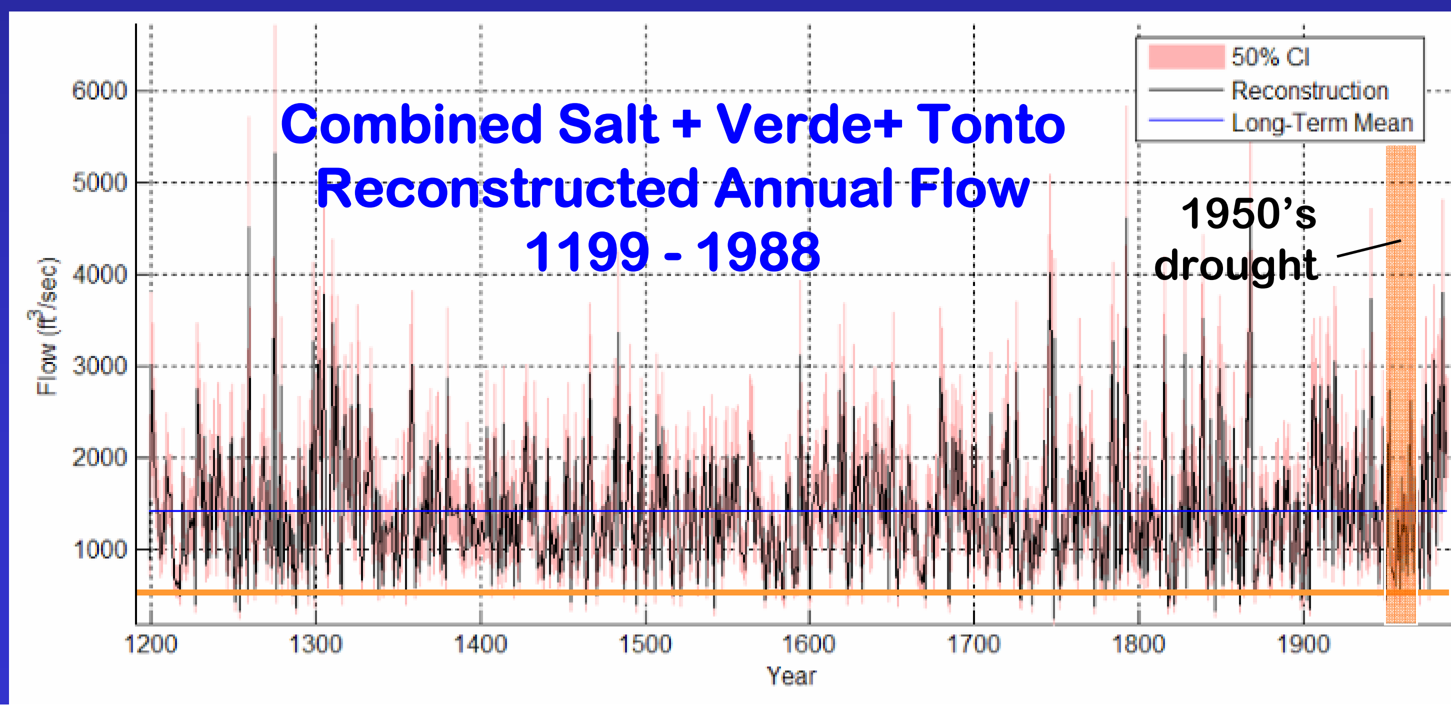
Tree-Ring Streamflow Reconstructions:





Tree-ring sites used in the reconstruction

Delivering more than power.



Hirschboeck & Meko
2005 SRP Final Report

www.ltrr.arizona.edu/srp

Paleo-Stage Indicators (PSI):

PALEOFLOOD (def)

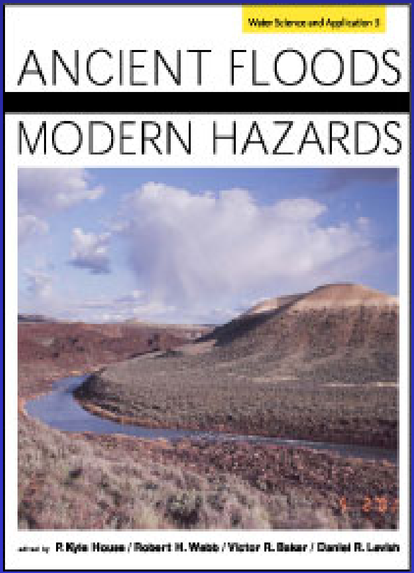
A past or ancient flood event which occurred prior to the time of human observation or direct measurement by modern hydrological procedures.

Recent or modern events may also be studied using paleoflood analytical techniques:

HISTORICAL FLOOD

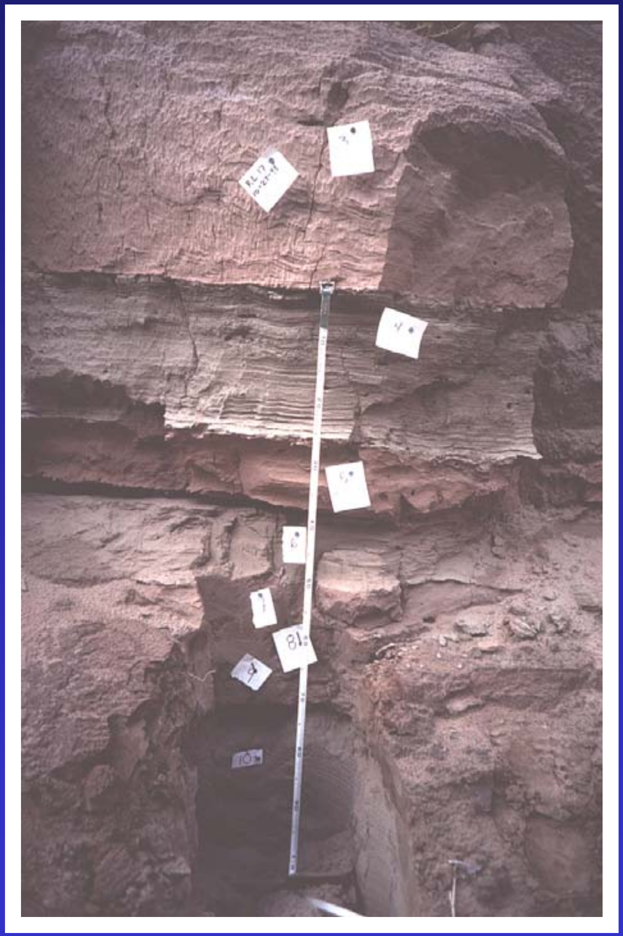
Flood event documented by human observation and recorded prior to the development of systematic streamflow measurements

EXTREME FLOOD IN UNGAGED WATERSHEDS



House, Webb, Baker & Levish (2002) American Geophysical Union

Paleoflood Deposits . . .



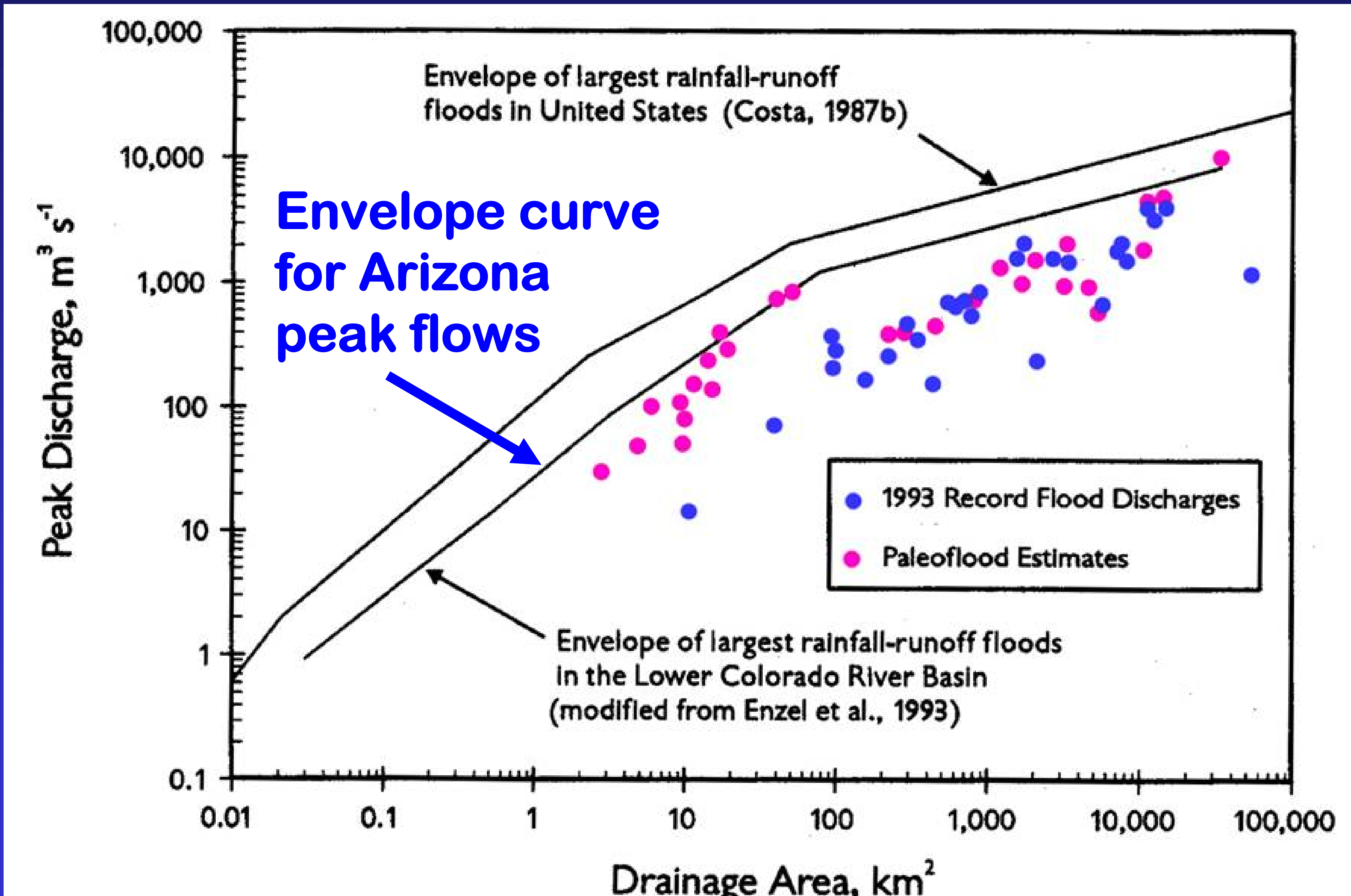
-- not filtered through a biological response (unlike tree rings)

-- *direct* physical evidence of extreme hydrologic events

-- selectively preserve evidence of only the largest floods . . .

. . . precisely the information that is lacking in the short gaged discharge records of the observational period

Compilations of paleoflood records combined with gaged records suggest there is a natural, upper physical limit to the magnitude of floods in a given region.



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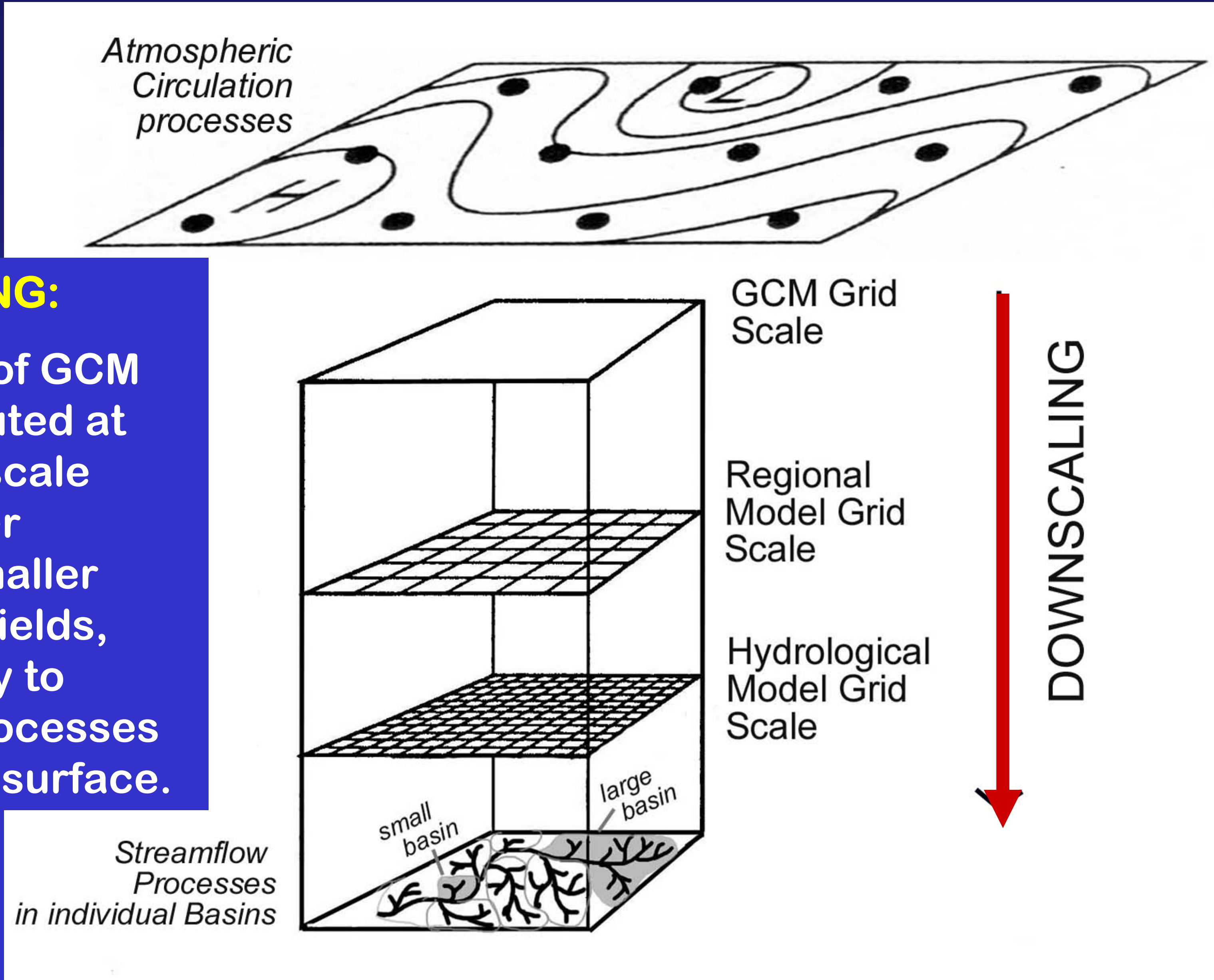
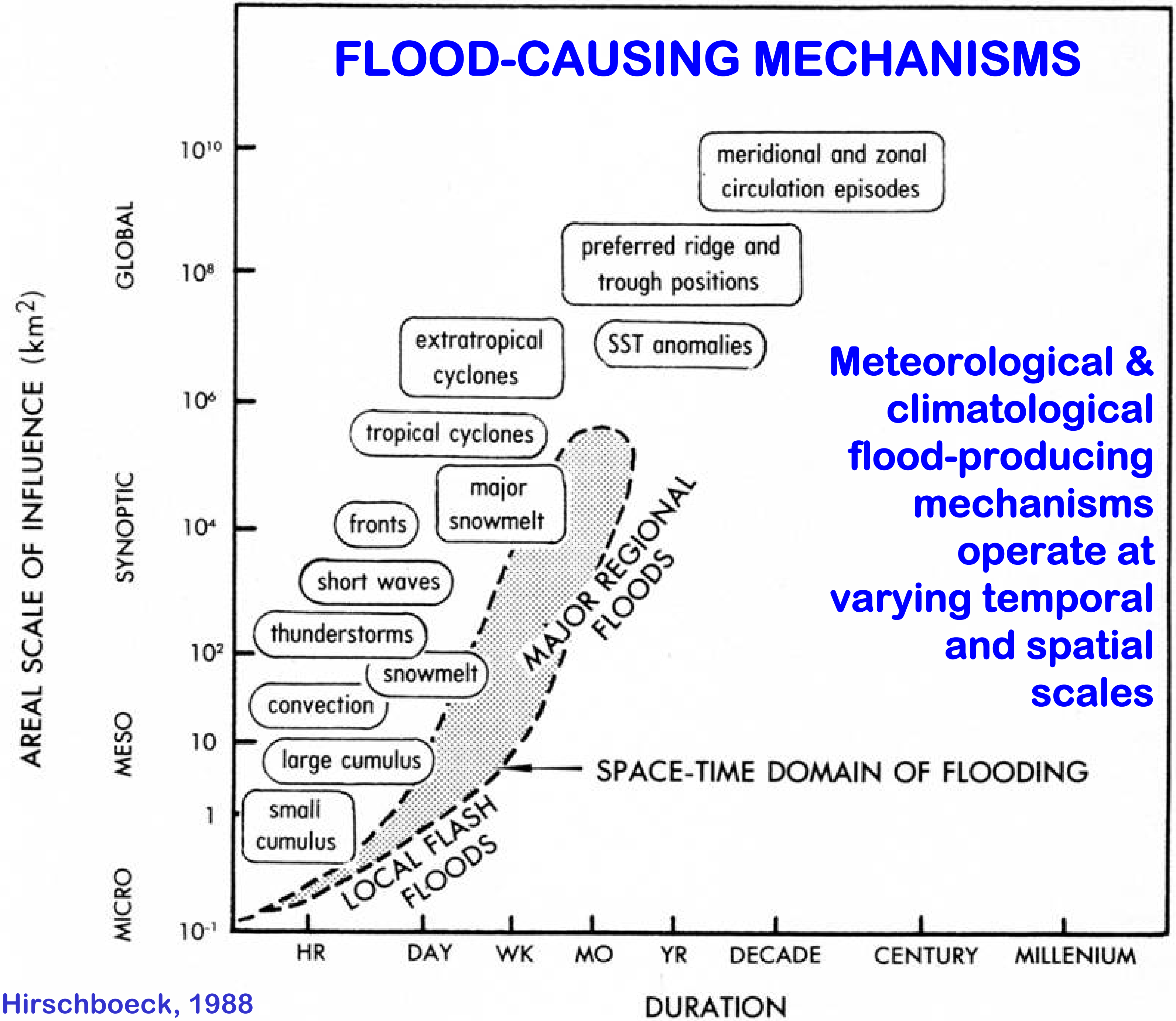
DOWNSCALING:

Interpolation of GCM results computed at large spatial scale fields to higher resolution, smaller spatial scale fields, and eventually to watershed processes at the Earth's surface.



Hirschboeck 2003 "Respecting the Drainage Divide" *Water Resources Update* #126 UCOWR *http://www.ucowr.siu.edu/updates/126/index.html*

FLOOD-CAUSING MECHANISMS



Meteorological & climatological flood-producing mechanisms operate at varying temporal and spatial scales

Hirschboeck, 1988

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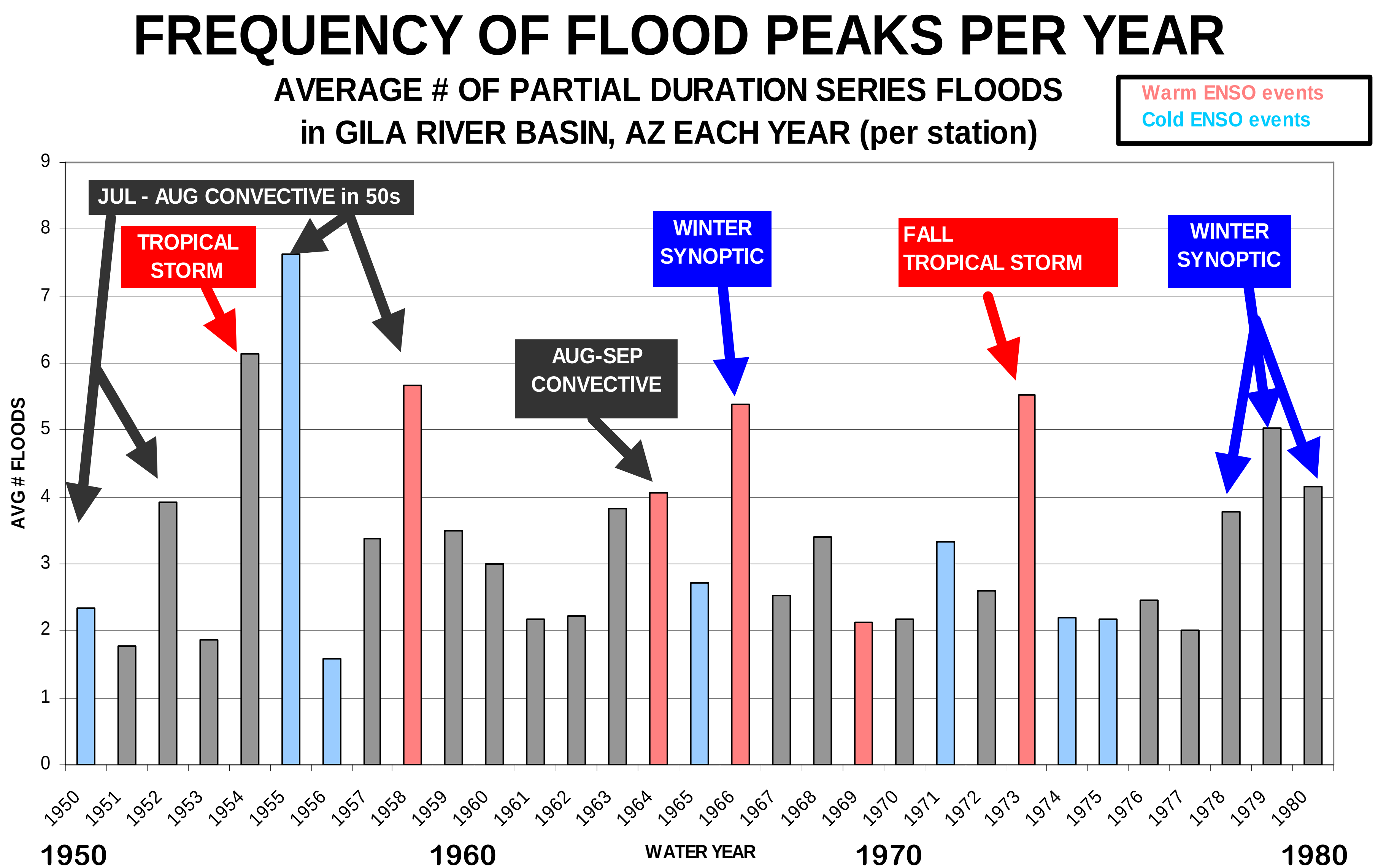
Interannual Variability of # of Floods (WY 1950-80)



FLOOD (DROUGHT) HYDROCLIMATOLOGY

Flood (drought) hydroclimatology is the analysis of flood (drought) events within the context of their history of variation

- in <u>magnitude, frequency, seasonality</u>

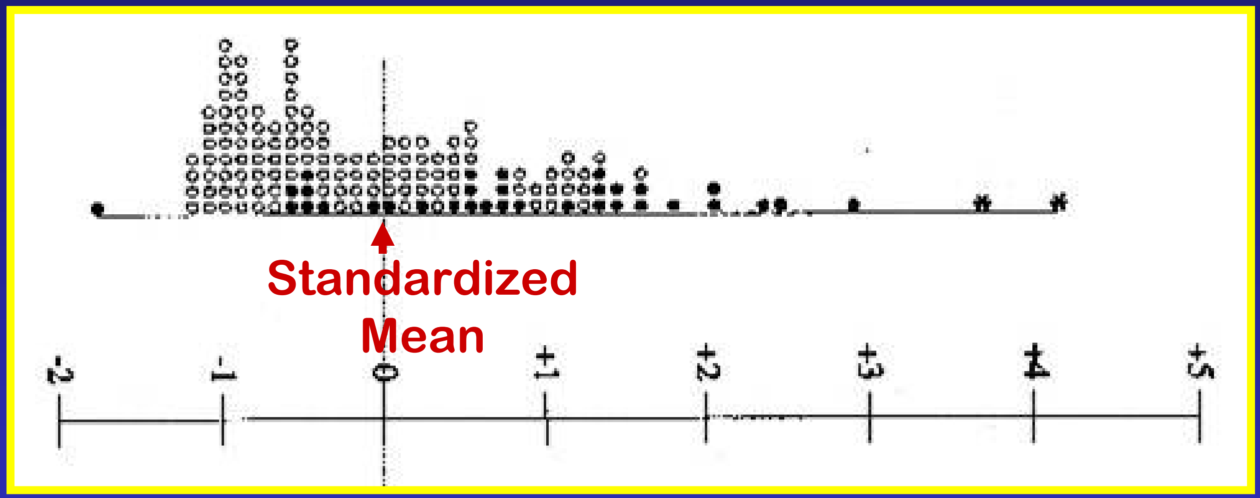
- over a relatively <u>long period of time</u>

- analyzed within the spatial framework of changing combinations of <u>meteorological causative mechanisms</u>

Adapted from Hirschboeck 1988
Flood Hydroclimatology

Gaged Flood Record -- Histogram

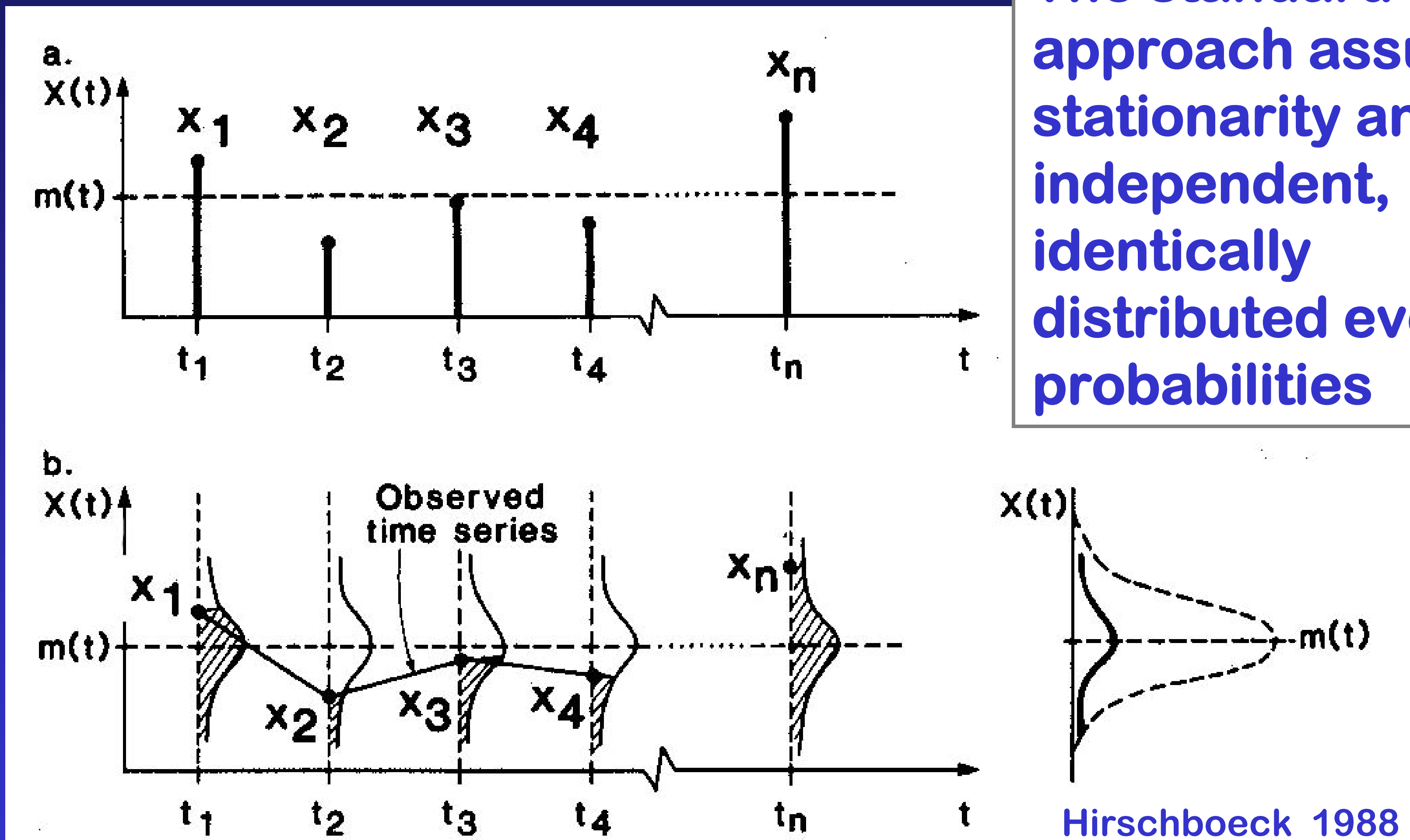
(Standardized Discharge Classes)



SKEWED DISTRIBUTION

Extreme events → tails of distribution

The Standard Time Series Assumption

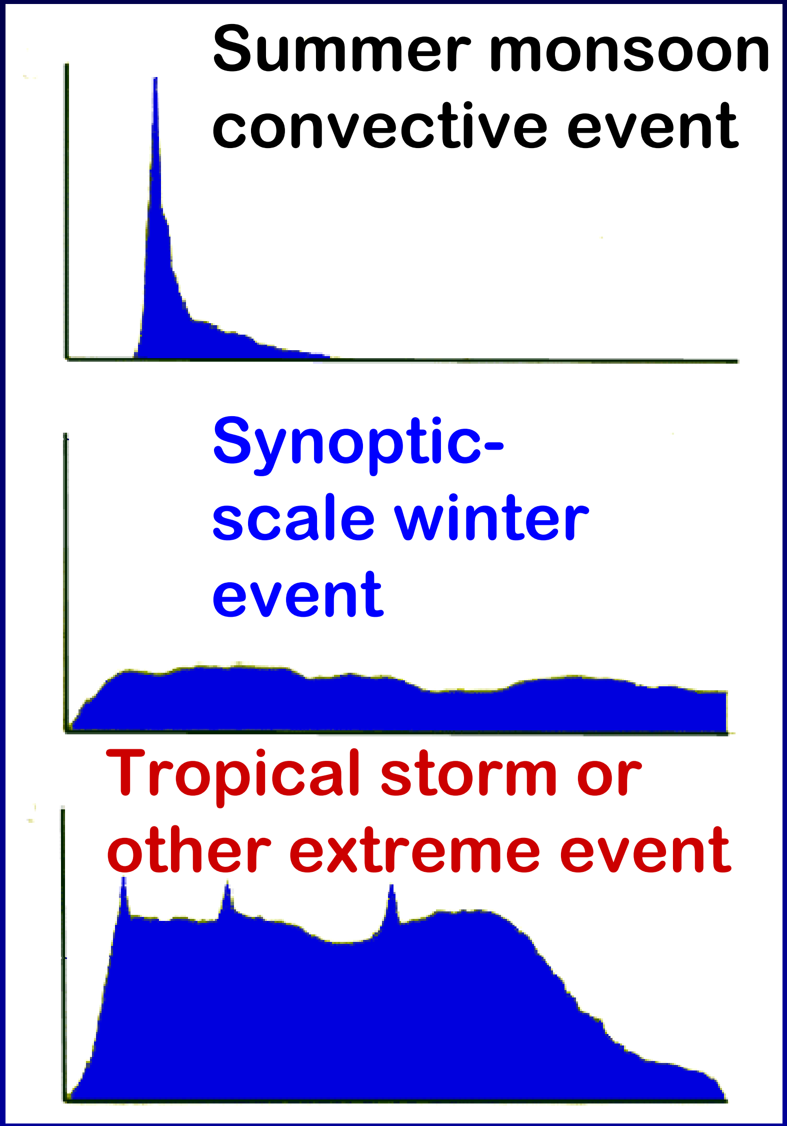


The standard approach assumes stationarity and independent, identically distributed event probabilities

Events at each point in time emerge from independently, identically distributed probabilities

. . . but are all floods alike?

The type of storm influences the shape of the hydrograph and the magnitude & persistence of the flood peak



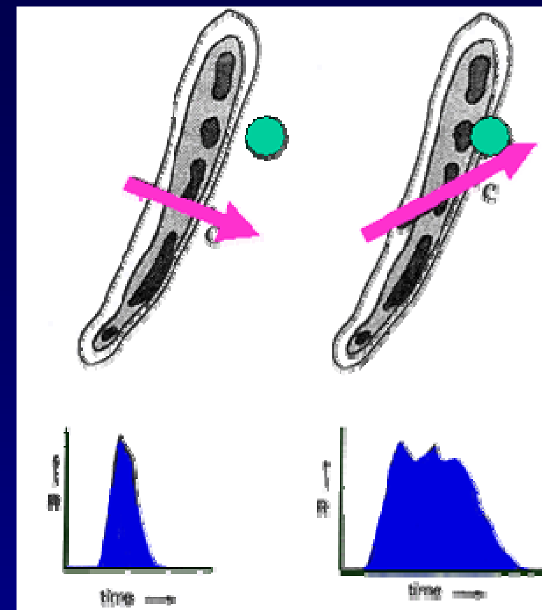
This can vary with basin size (e.g. convective events are more important flood producers in small drainage basins in AZ)

Hirschboeck 1987a

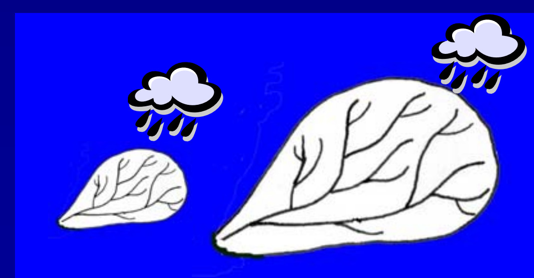
In addition, extreme flow events can emerge from synergism in:

The way in which rainfall is delivered

- in both space (e.g., storm movement, direction)
- and time (e.g., rainfall rate, intensity)
- over drainage basins of different sizes & orographies



from Doswell et al. (1996)



Therefore -- hydroclimatic subgroups may vary with drainage area in the same watershed

Causative mechanisms:

- precipitation type
- storm characteristics
- steering mechanisms
- synoptic pattern / storm track
- antecedent conditions

This framework of analysis allows a flood time series to be combined with climatic information

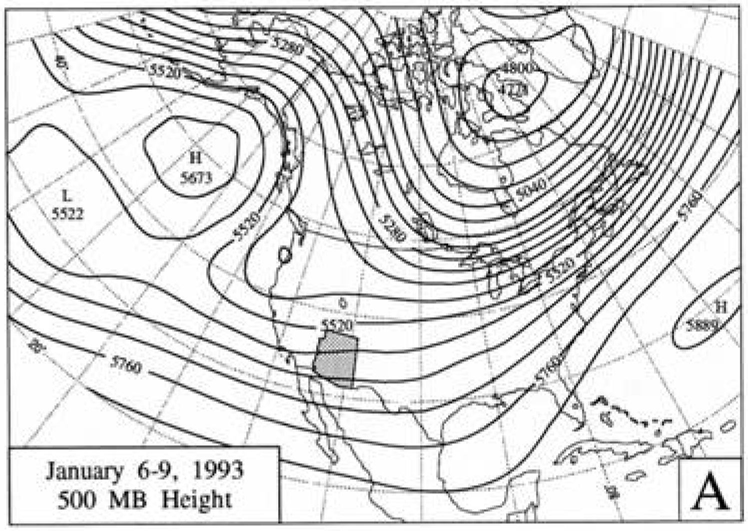
To arrive at a PROCESS-based mechanistic understanding of long-term flooding variability and its probabilistic representation.

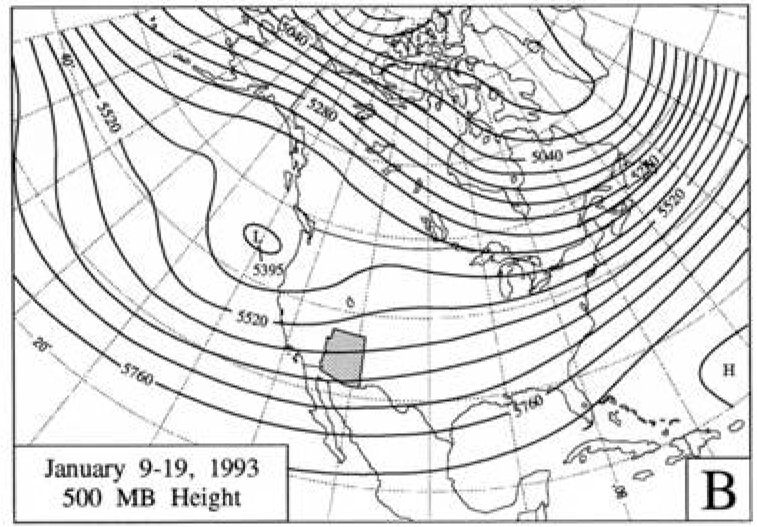
(This can also be done with droughts.)

Example: SYNOPTIC "EDDY FLOW" ALONG DIFFERENT WINTER STORM TRACKS

TRANSIENT EDDIES:

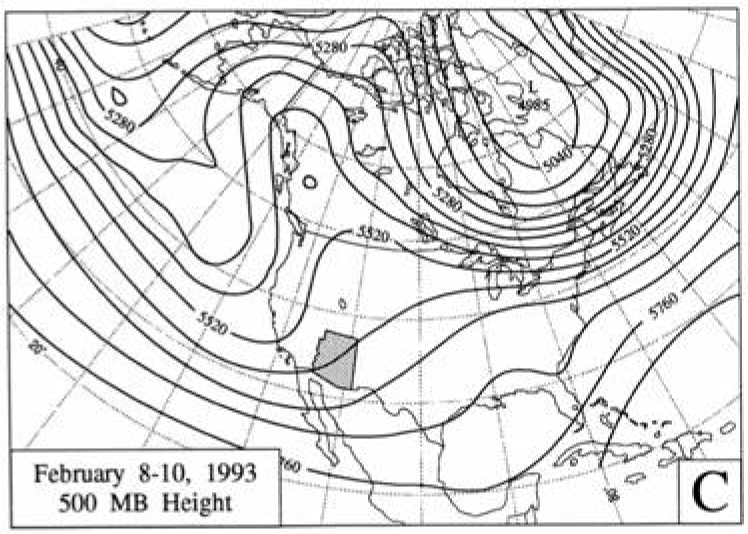
Cold storm sequence on W-E track
➔ snow

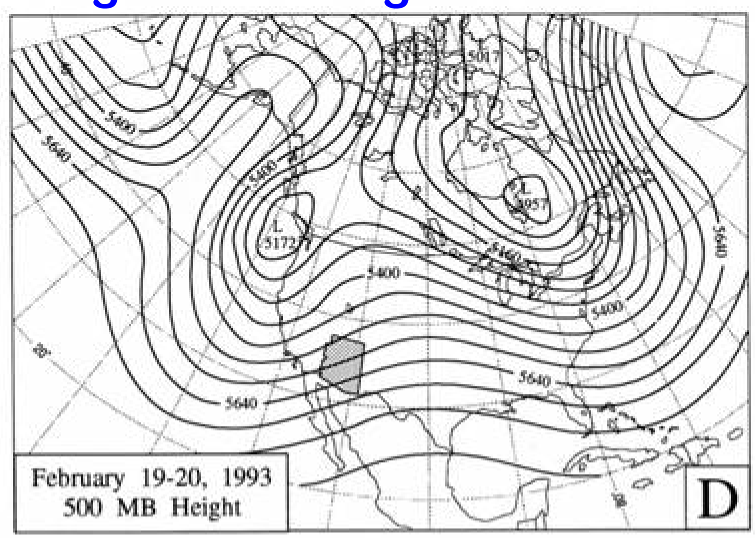




Process-based understanding of flood origins

Warm storm sequence on SW-NE track
➔ rain-on-snow





From: House & Hirschboeck 1997

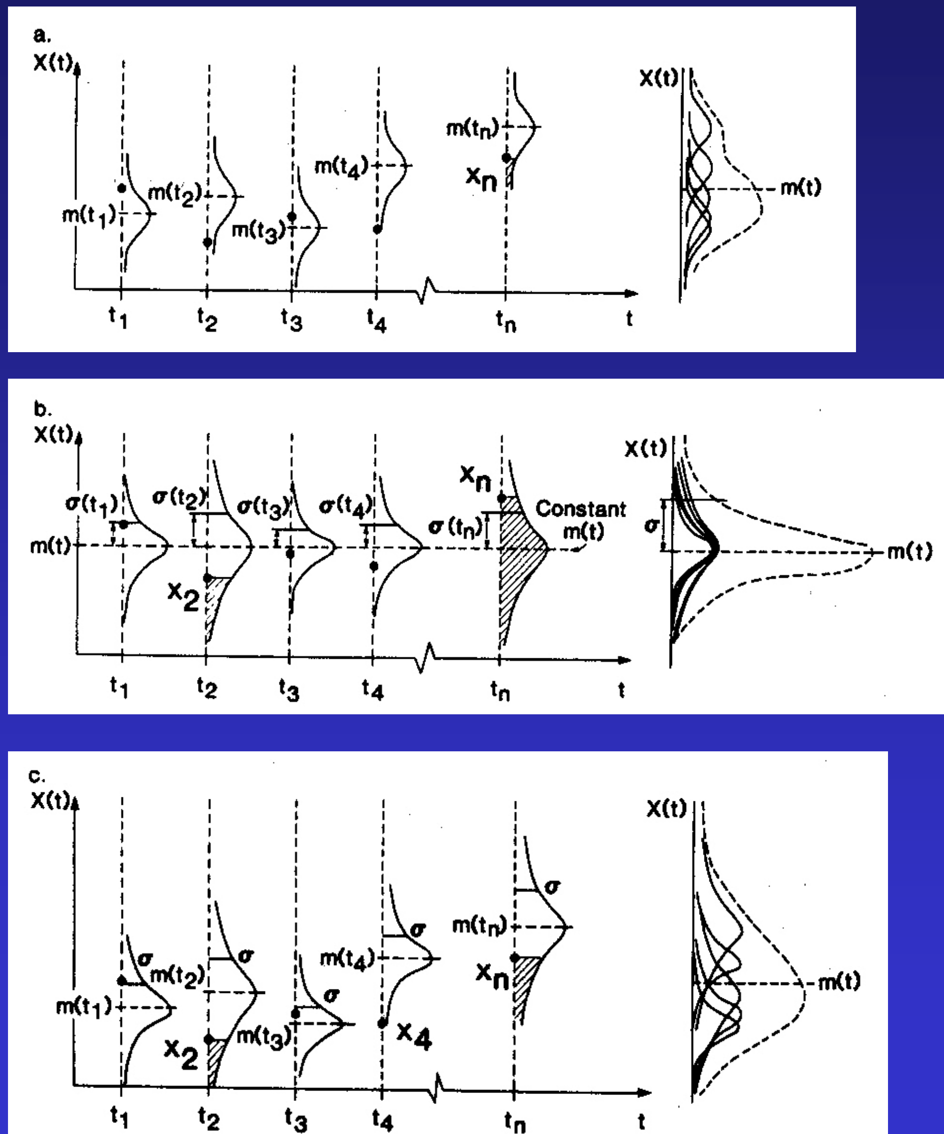
Record-breaking floods of winter 1992-93 in Arizona

Process-Based Conceptual Framework for Hydrologic Time Series:

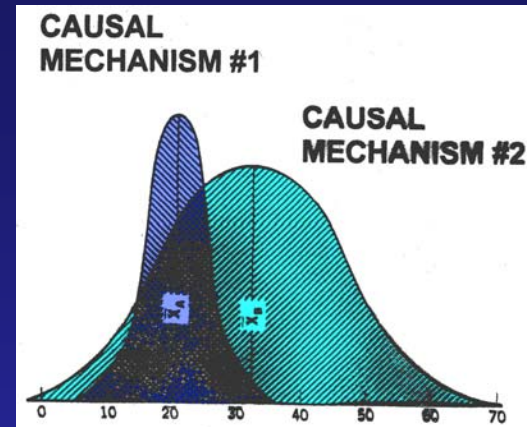
Time-varying means

Time-varying variances

Both

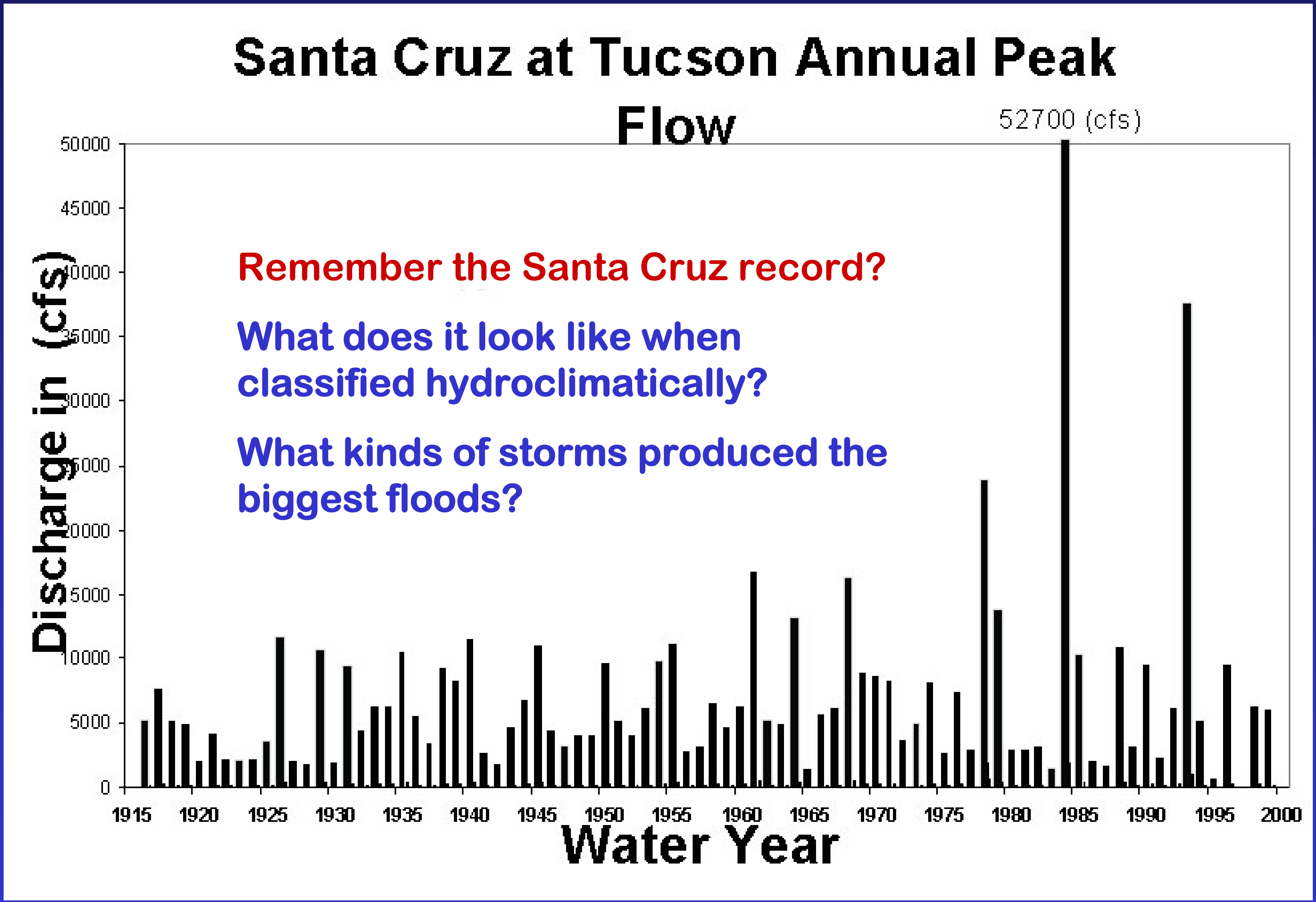


Hirschboeck, 1988

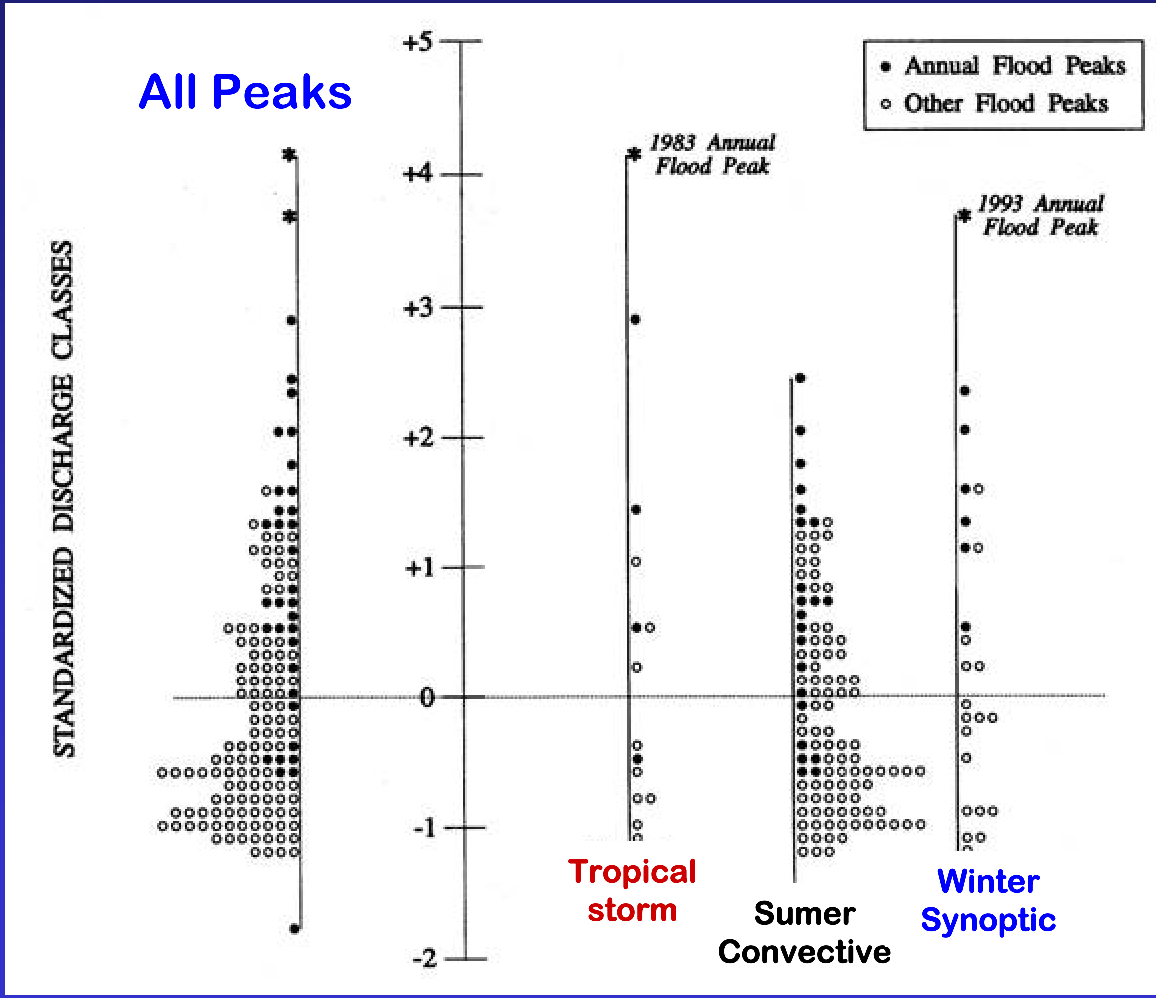


Mixed frequency distributions may arise from:

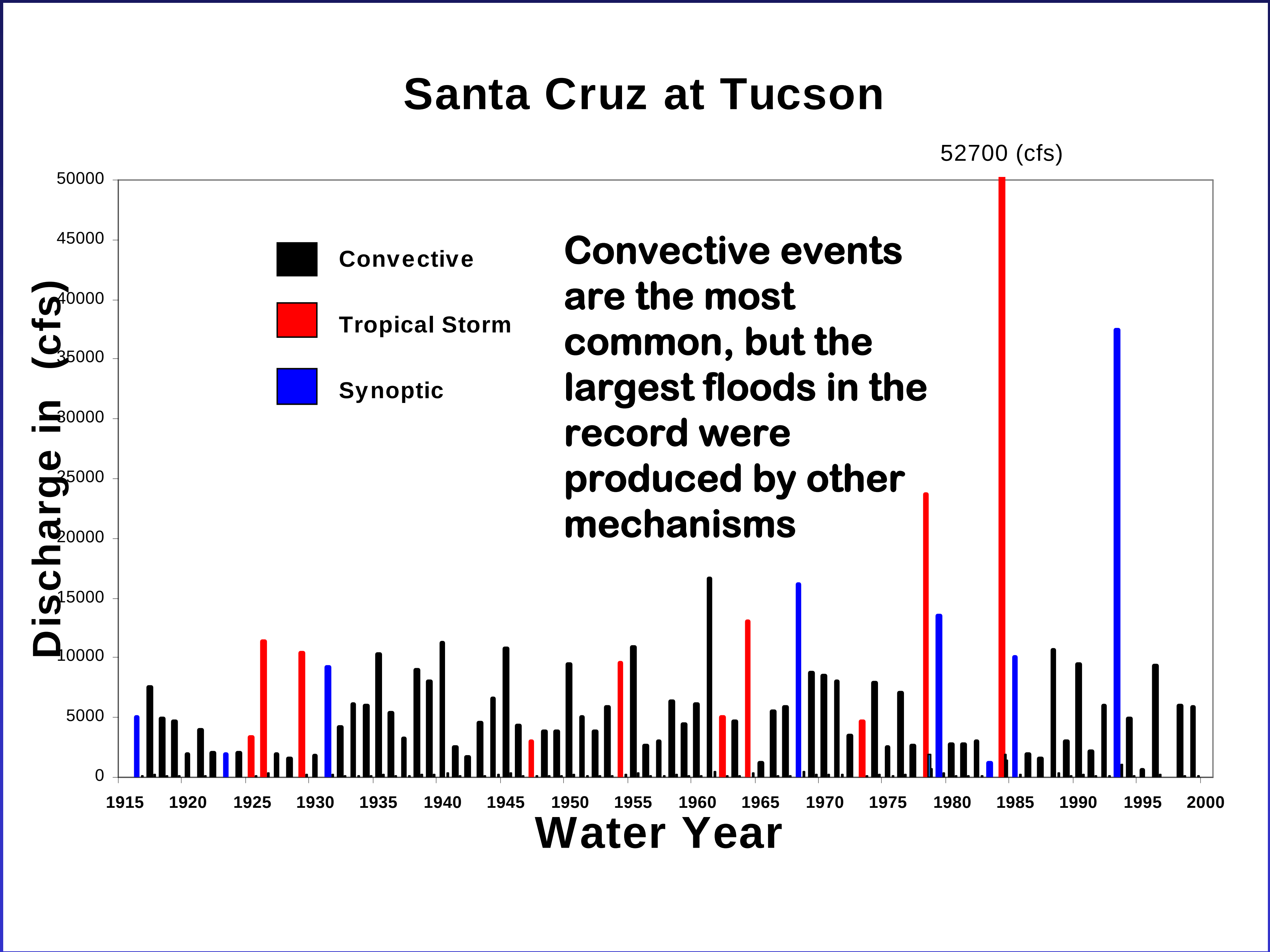
- storm types
- synoptic patterns
- ENSO, etc. teleconnections
- multi-decadal circulation regimes


Santa Cruz at Tucson Annual Peak Flow
52700 (cfs)
Discharge in (cfs)
Water Year
Remember the Santa Cruz record?
What does it look like when classified hydroclimatically?
What kinds of storms produced the biggest floods?

Santa Cruz River at Tucson
Peak flows separated into hydroclimatic subgroups

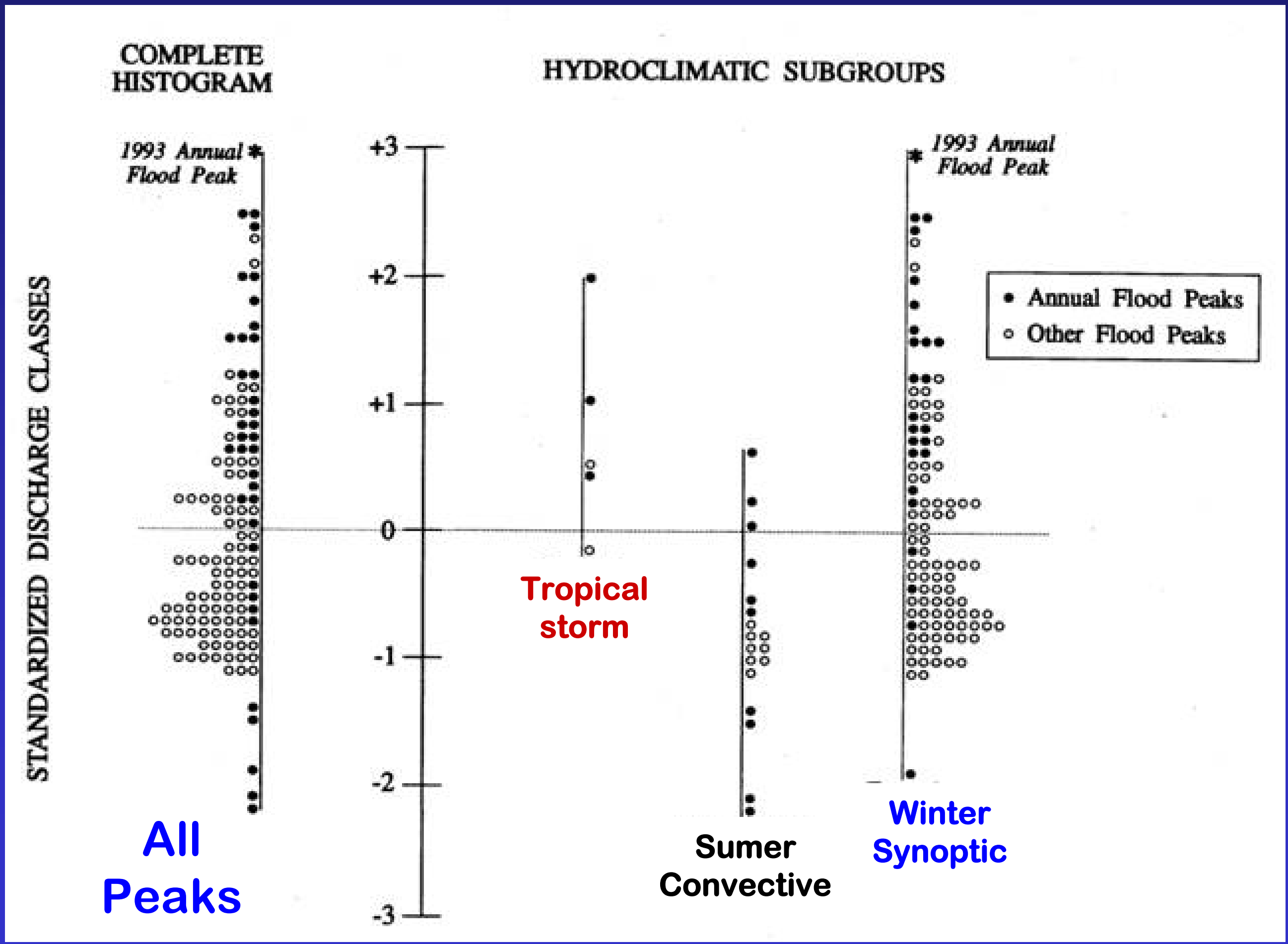


Hirschboeck et .al. 2000

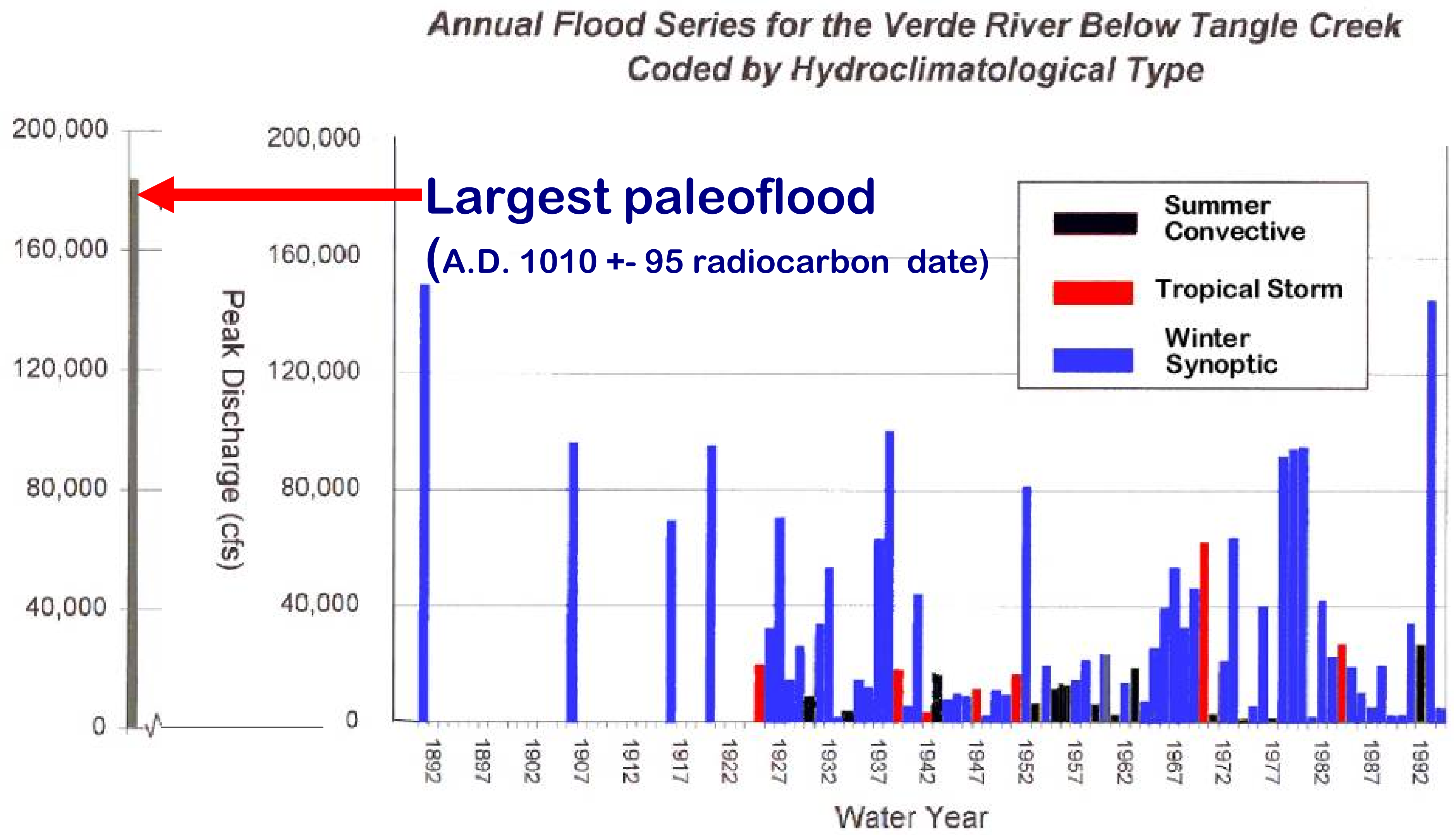

Santa Cruz at Tucson
52700 (cfs)
Convective
Tropical Storm
Synoptic
Convective events are the most common, but the largest floods in the record were produced by other mechanisms
Discharge in (cfs)
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
1915
1920
1925
1930
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
Water Year

Verde River below Tangle Creek

Peak flows separated into hydroclimatic subgroups



Hirschboeck et .al. 2000

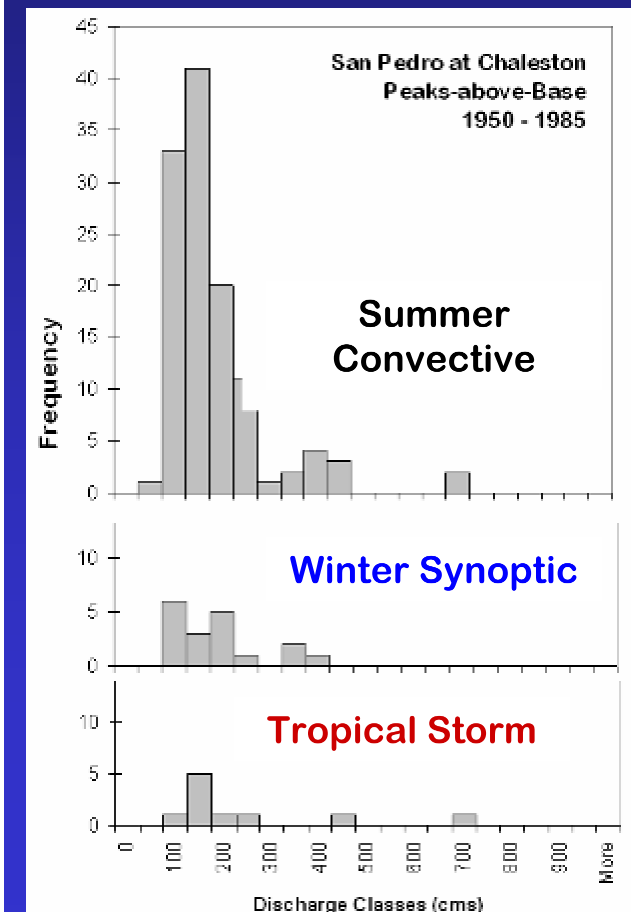


Annual Flood Series for the Verde River Below Tangle Creek
Coded by Hydroclimatological Type
Largest paleoflood
(A.D. 1010 +- 95 radiocarbon date)
Summer Convective
Tropical Storm
Winter Synoptic
Peak Discharge (cfs)
200,000
160,000
120,000
80,000
40,000
0
1892
1897
1902
1907
1912
1917
1922
1927
1932
1937
1942
1947
1952
1957
1962
1967
1972
1977
1982
1987
1992
Water Year

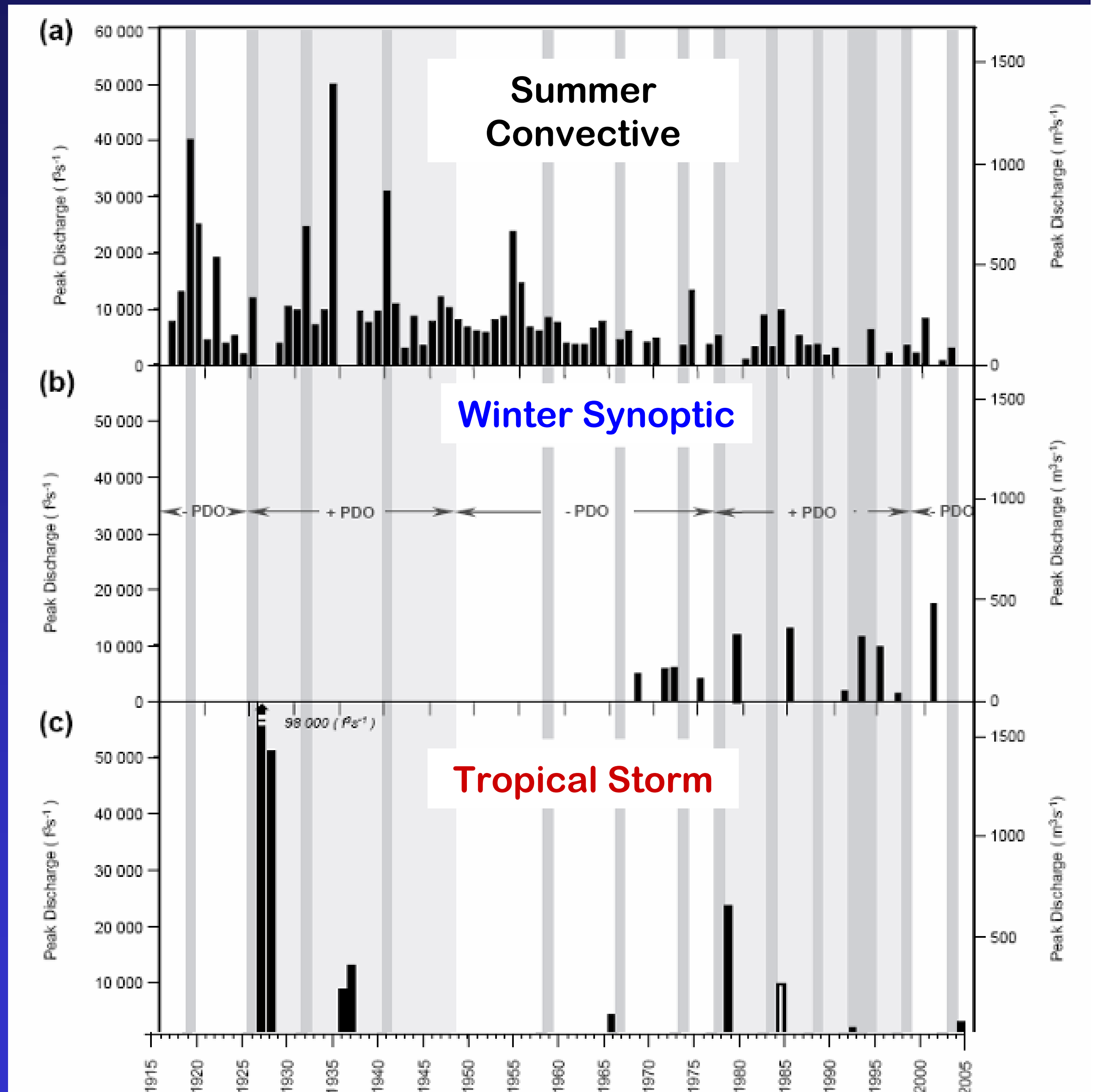
San Pedro at Charleston

Peak flows separated into hydroclimatic subgroups

from: MacNish, R, Hirschboeck, K., Baird, K., and Maddock. T.i *in* Stromberg and Tellman *(forthcoming)*

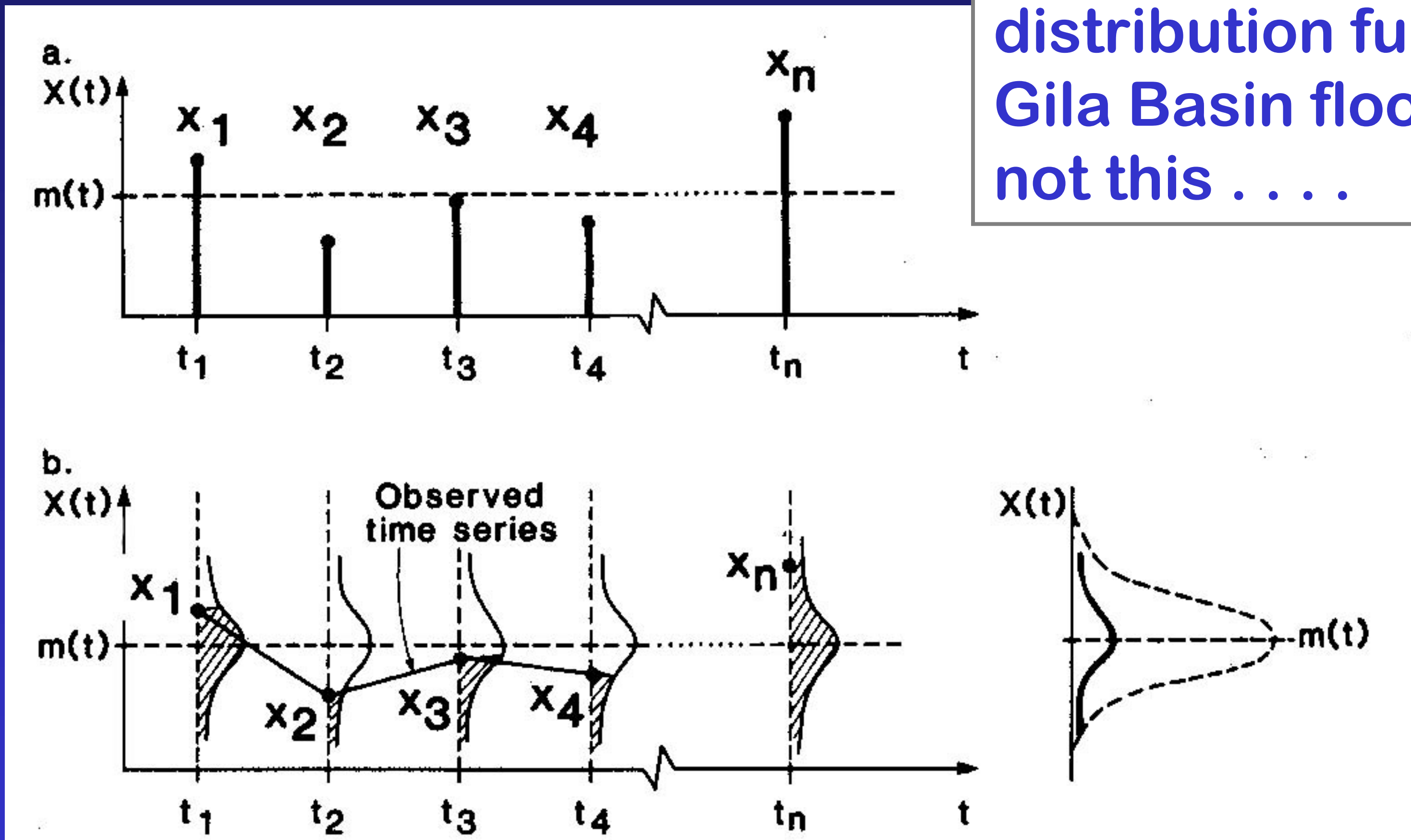


El Nino years



1915 1960 2005

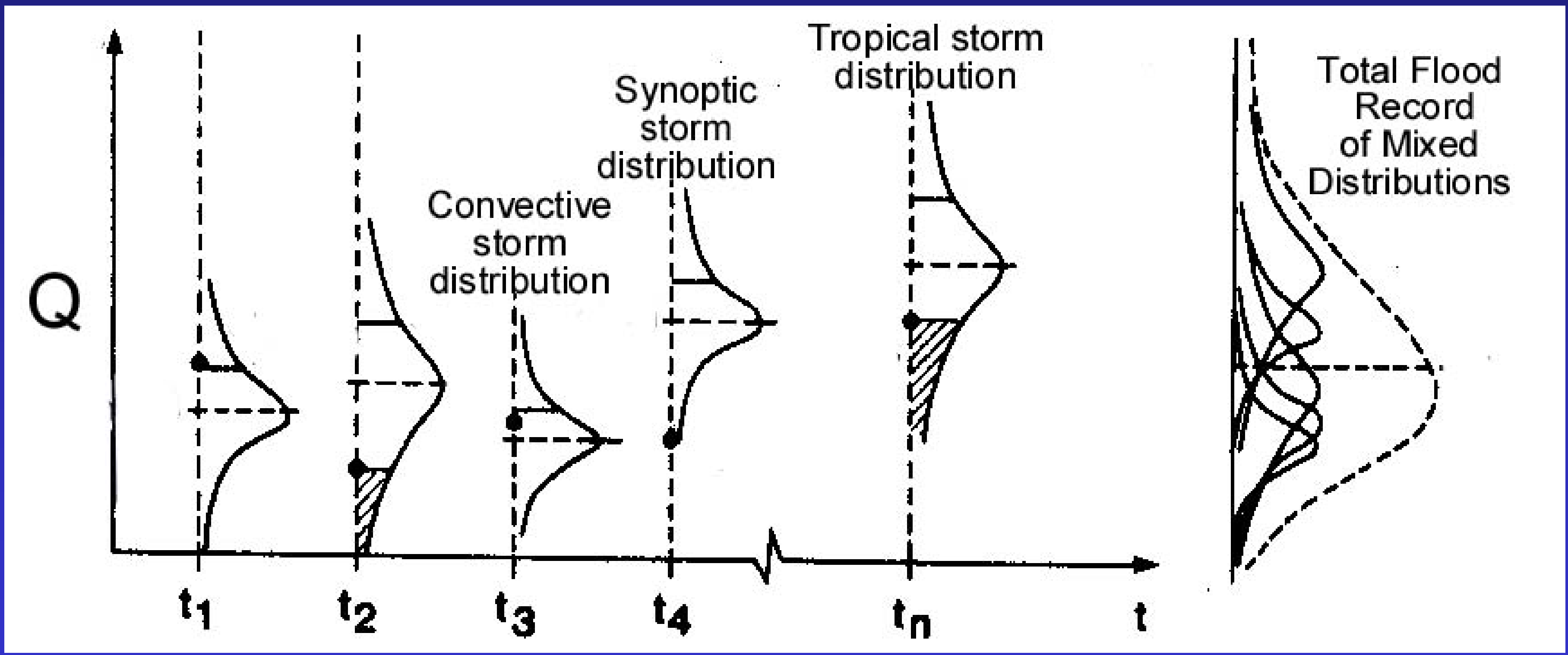
Based on these results we can re-envision the underlying probability distribution function for Gila Basin floods to be not this . . . .



. . . but this:

Alternative Model to Explain How Flood Magnitudes Vary over Time

Schematic for Arizona riparian systems based on different storm types

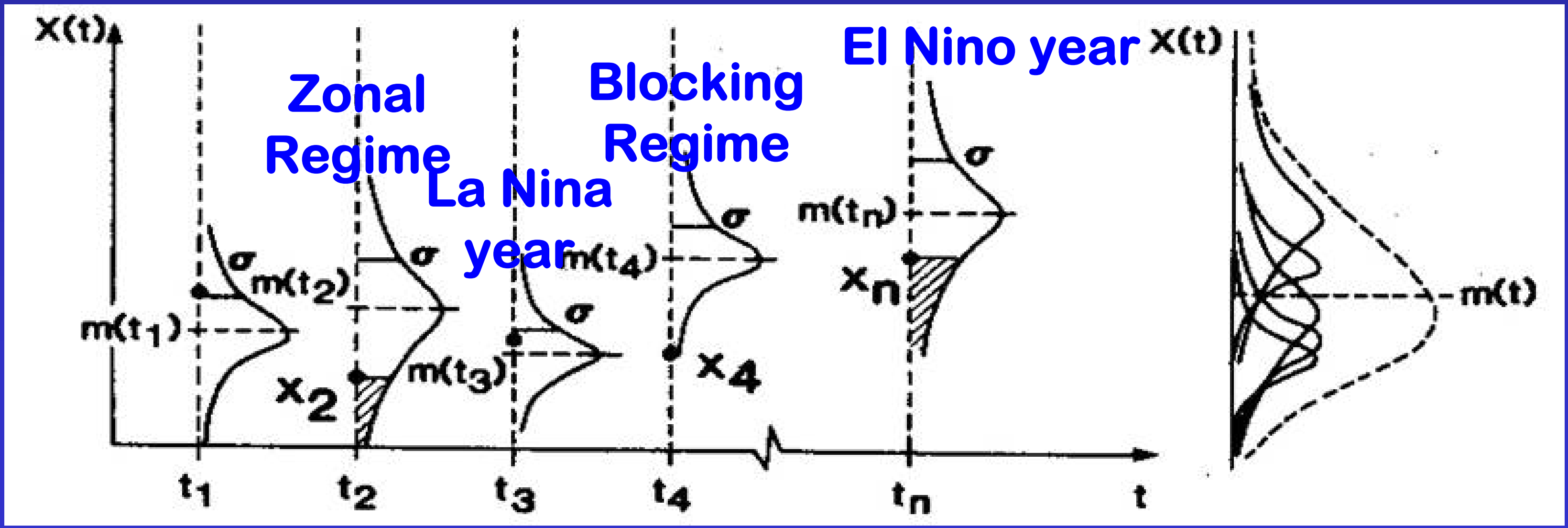


Varying mean and standard deviations due to different causal mechanisms

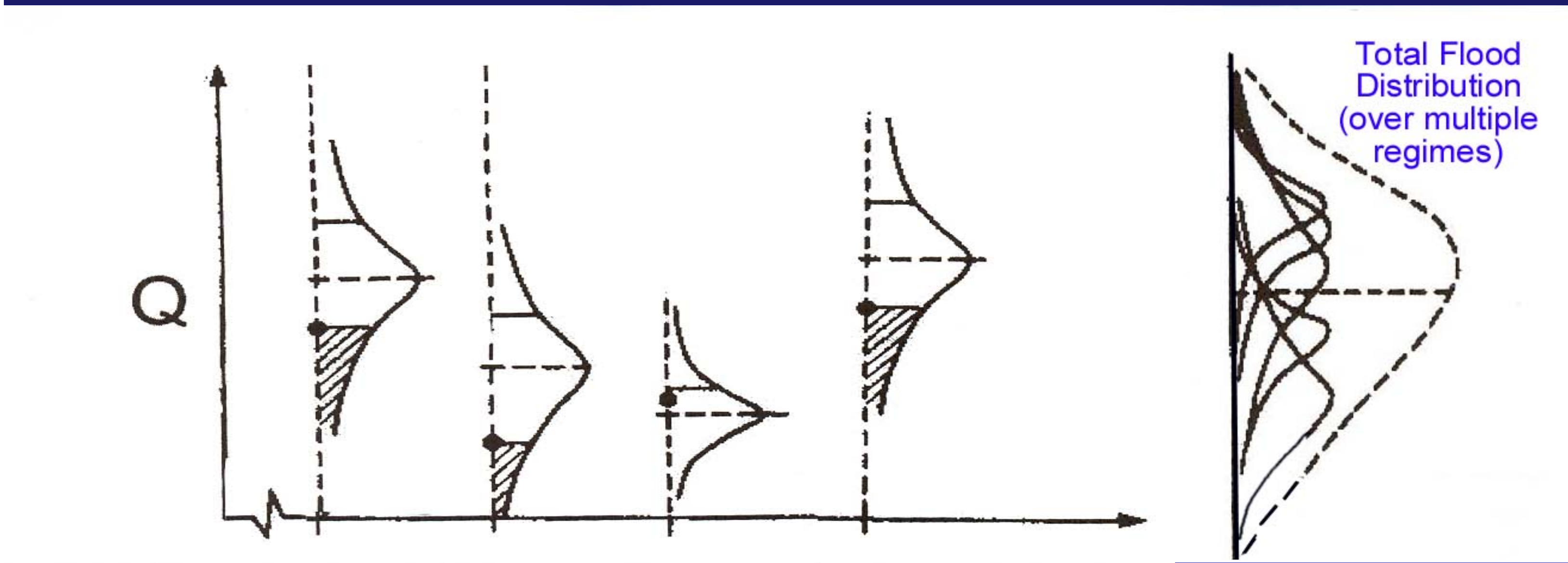
. . . or this:

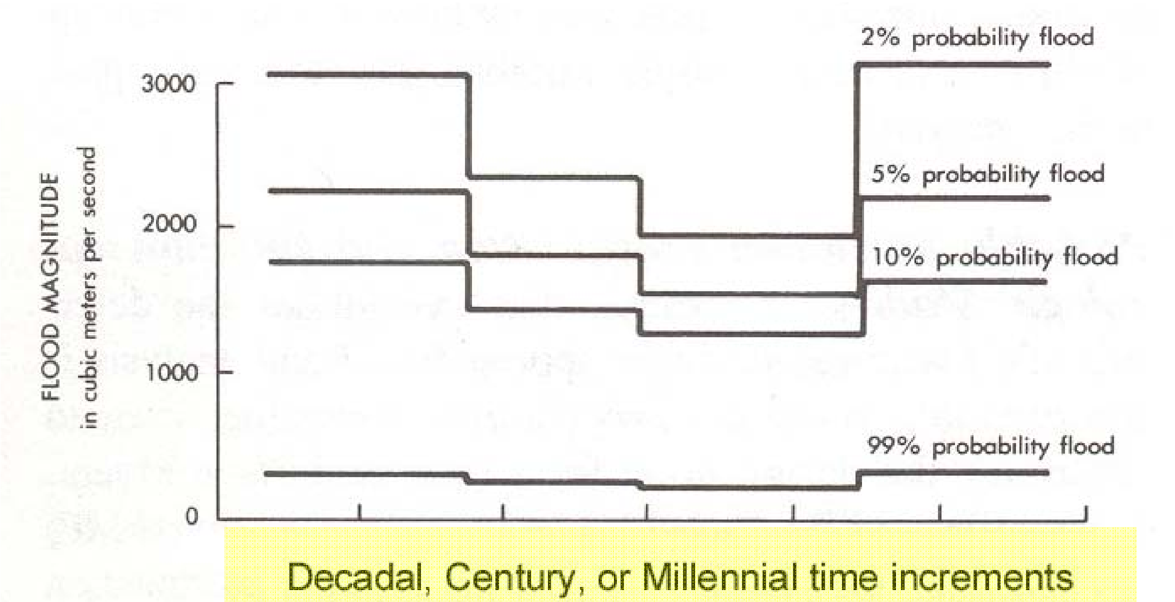
Conceptual Framework for
Circulation Pattern Changes

When the dominance of different types of flood-producing mechanisms or circulation patterns changes over time, the probability distributions of potential flooding at any given time (t) may be altered.



. . . or this: Conceptual Framework for Low-Frequency Variations and/or Regime Shifts:



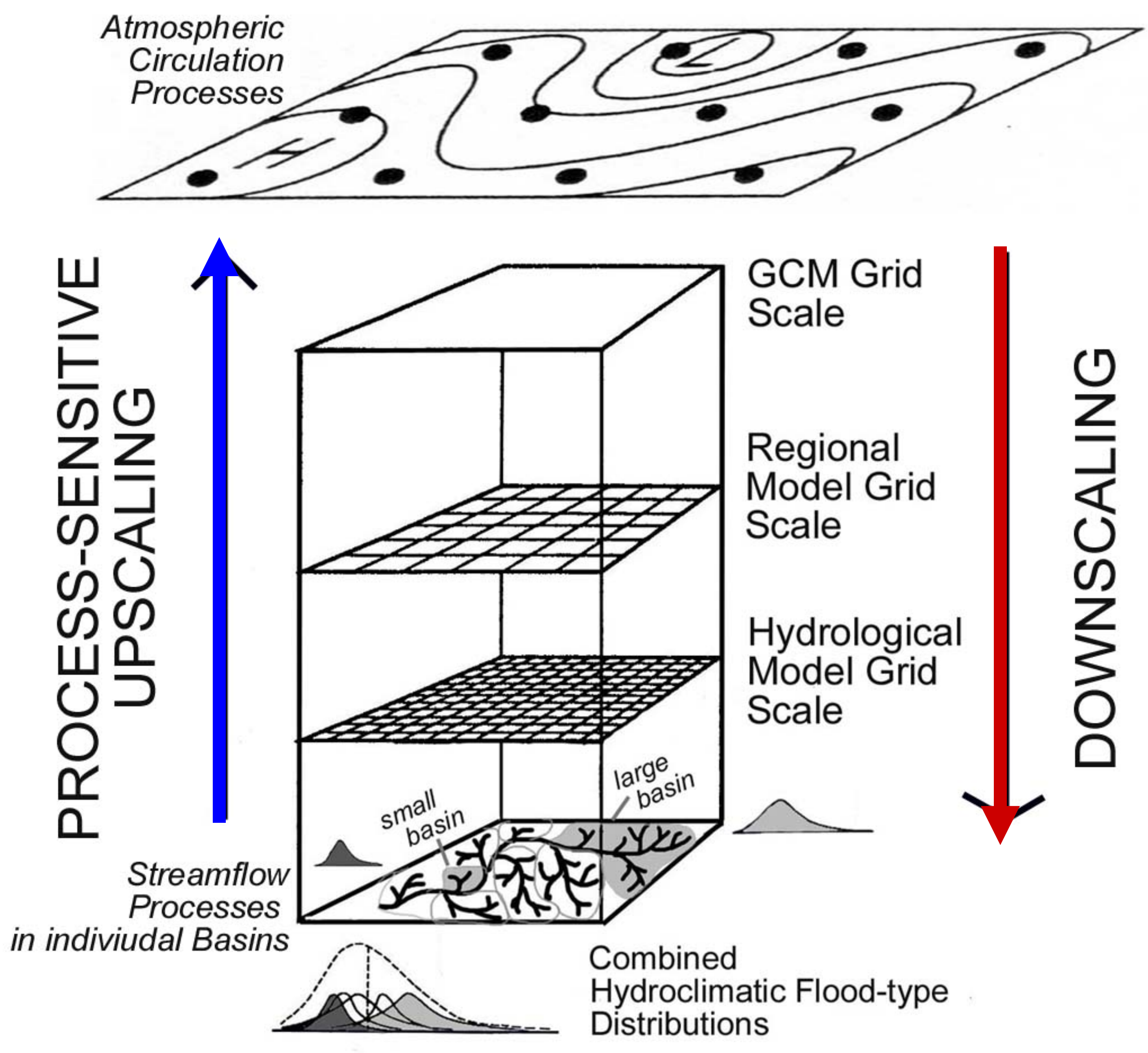


A shift in circulation or SST regime (or anomalous persistence of a given regime) will lead to different theoretical frequency / probability distributions over time.

Hirschboeck 1988

By associating seasonal and long-term variations in a stream's hydrograph with storm types and the synoptic atmospheric circulation patterns that deliver them . . .

. . . a PROCESS-BASED "upscaling" approach provides an alternative way to bridge the gaps between local, regional, and global scales of hydroclimate information and future climate projections.


Atmospheric
Circulation
Processes
H
L
PROCESS-SENSITIVE
UPSCALING
GCM Grid
Scale
Regional
Model Grid
Scale
Hydrological
Model Grid
Scale
DOWNSCALING
small
basin
large
basin
Streamflow
Processes
in indiviudal Basins
Combined
Hydroclimatic Flood-type
Distributions

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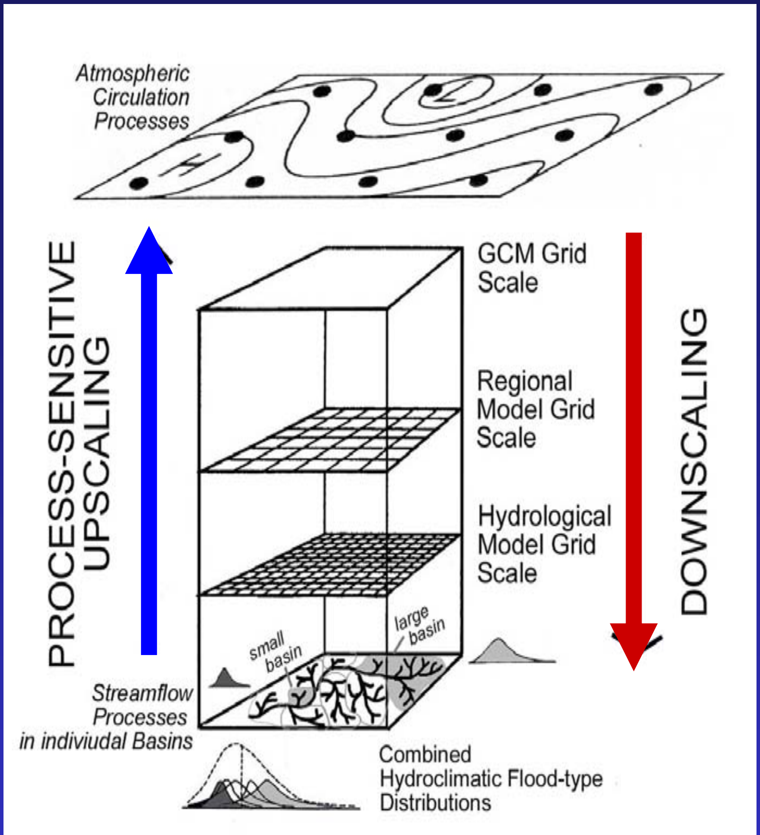
IV. Concluding Remarks

Summary

Attention to some very basic hydrologic elements at the <u>local</u> and <u>regional</u> scale . . .

. . . . especially as they are manifested in a stream's past history and its present individual mix of storms and processes . . .



. . . can provide a basis for a cross-scale approach to linking <u>GLOBAL</u> climate variability with <u>LOCAL</u> hydrologic variations in riparian areas.

1.
Conceptual Framework → Process Upscaling

For floods, paleofloods, or droughts, climatic changes can be conceptualized as time-varying atmospheric circulation regimes that generate a mix of shifting streamflow probability distributions over time.

This conceptual framework –
provides an opportunity to evaluate streamflow-based hydrologic extremes under a changing climate from the viewpoint of the riparian area itself, i.e. "process upscaling" in addition to "model downscaling."

2.
Regional Basin Differences

The interaction between storm properties and drainage basin properties (e.g. area, aspect, slope) plays an important role in the occurrence and magnitude of large floods both regionally and seasonally – and may result in different combinations of mixed distributions.

Understanding these regional basin differences is precisely what is needed to assess how projected climate changes will impact a given watershed.

3.
Usefulness of Paleo-record

Extending a streamflow record back in time with paleo -information can provide deeper insights into the natural variability of the stream.

Compilations of paleoflood records combined with gaged records suggest there is a natural, upper physical limit to the magnitude of floods in a given region.

Will this be true in the future? An envelope curve can be a useful tool for investigating this type of regional change in streamflow extremes.

4.

Mean Flow vs Transient "Eddies"

Shifts in storm track locations and other anomalous circulation behaviors (transient eddy flow) are clearly linked to unusual flood and drought behavior.

The dire model projections in Seager et al. 2007 were driven mostly by the mean flow, not the transient eddies which are important for determining where precipitation will occur.

Shifts in winter storm tracks (& eddies) are likely to be the factors most *directly* responsible for projected increases – or decreases -- in hydrologic extremes under a changing climate.

5.
Natural Variabiliy vs Anthropogenically Forced Model Projections

In contrast to historical droughts, future drying (in the models) is not linked to any particular pattern of change in sea surface temperature but seems to be the result of an overall surface warming driven by rising greenhouse gases.

El Niño and La Niña factors should still come into play . . . but will their influence and effects be the same?

6.
Summer Uncertainty

Future projections for the summer monsoon rainy season are still very uncertain.

-- will convective storms increase due to warmer temperatures and more precipitable water vapor?

-- or will subtropical drying suppress the rains?

CLIMAS
Climate Assessment for the Southwest

Proposed project to add flood & drought hydroclimatology information for specific gages to this webpage:

Arizona Flood Warning & Drought Monitoring

Home | Lakes/Dams | Rivers/Washes | Precipitation | Weather | Drought | Tools | Links

Welcome to the Arizona Flood Warning and Drought Monitoring Webpage

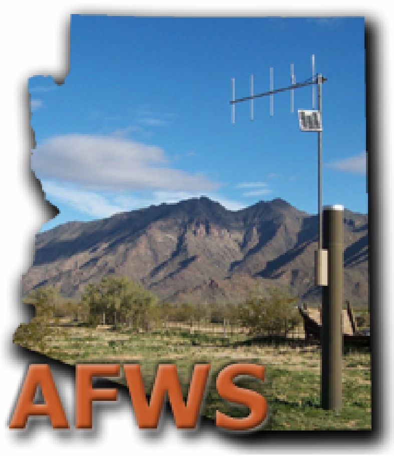


Photo: Steve Waters, FCDMC

Webpage participants are committed to providing weather, precipitation and stream flow information in "real time" in order to monitor and assess the potential risk for flooding in areas within Arizona.

The gauges on this site are organized by county and watershed. Please click here to view a county or watershed map.

The engine behind this webpage is the Multi-Agency Task Force, a group comprised of federal, state, and local agencies working to enhance communication, particularly during times of severe weather. Read about the background of the Arizona Flood Warning System and see the list of participating agencies.

http://data.afws.org/sui/frontPage.aspx