Needs for Seasonal Precipitation Forecasting – CA Perspective

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Outline

- Institutional & hydrologic setting
- Decision context, drought example
- Where do we go from here?

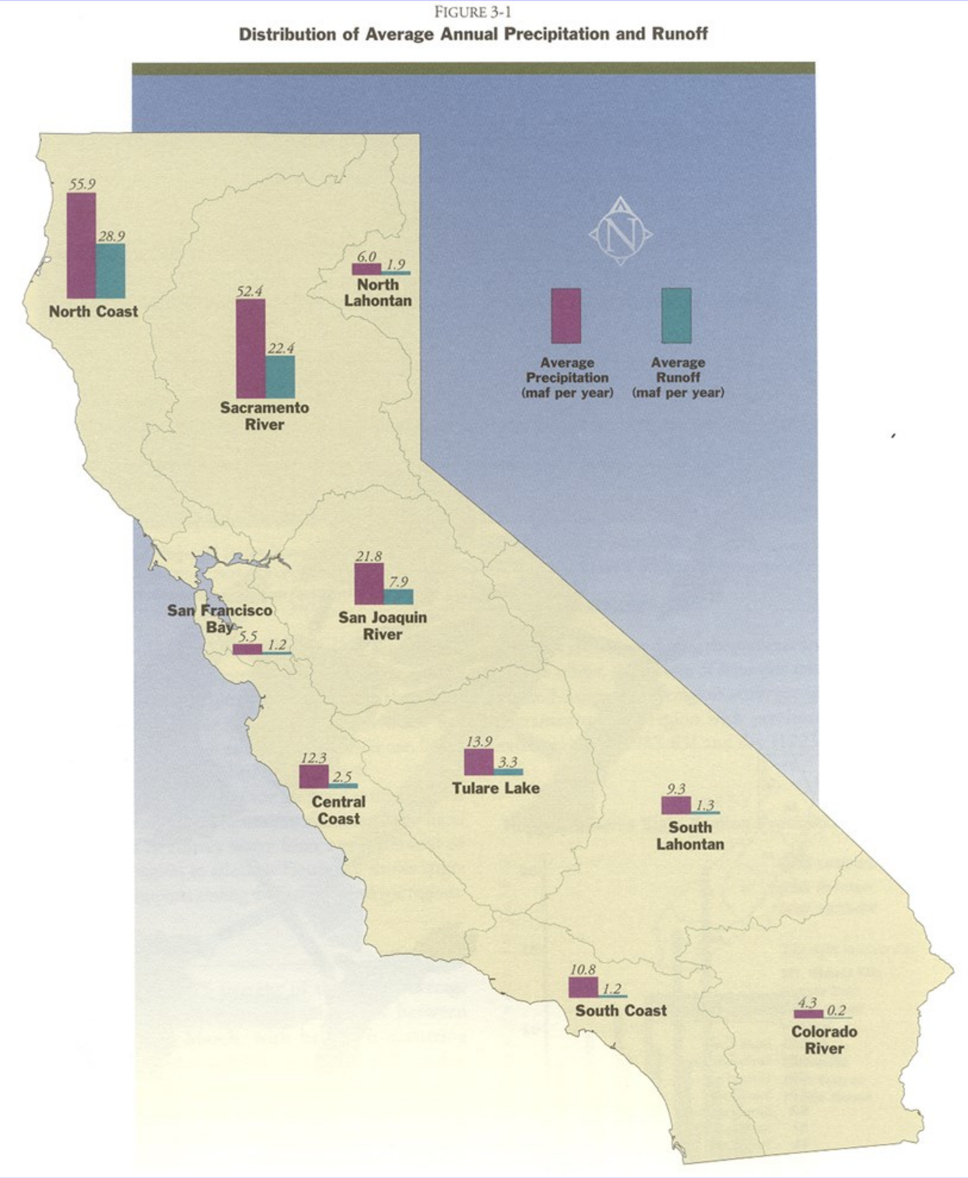
Calif Dept of Water Resources

- Operates State Water Project (4 MAF contractual allocations)
- Operates Sacramento River Flood Control Project, provides flood forecasting and flood operations services
- Manages data programs: California Data Exchange Center, Calif Cooperative Snow Surveys program, groundwater, land and water use, etc
- Administers local agency financial assistance programs, state water supply planning programs, and dam safety program

State Water Resources Control Bd

- Administers state and federal (Clean Water Act) water quality regulatory programs
- Administers water rights
- Administers local agency water quality financial assistance programs, state water quality planning programs
- As of July 2014, administers drinking water regulatory program

Hydrologic Setting




Major Rivers
State Projects
Federal Projects
Local Projects
Redding
Sacramento
San Francisco
Fresno
Los Angeles
San Diego

California's Annual Water Supplies – Key Points

- Average annual statewide precipitation
  - 75% in November – March
  - 50% in December – February
- Spring snowmelt runoff fills reservoirs
- Annual water budget determined by small number of storms
  - Atmospheric river storms

Improving Seasonal Forecasting – the Time is Ripe

- California's drought (specific direction to CDWR in Jan 2014 Emergency Proclamation to improve seasonal forecasting)
- Implementing forecast-based reservoir operations, to improve operational efficiency
- Tool for adaptation to long-term climate change (loss of mountain snowpack)

High-Priority Questions

- It’s November – will this water year be wet or dry? (for drought preparedness & response)
- It’s mid-January – will the rest of the season be wet or dry? (informing reservoir operations generally)

California's 2012-2015 Drought Example

- Lead-time for decision-making & response actions (longer is better!!!)
  - Governor's emergency proclamations, executive orders
  - State budget process, emergency funding legislation
  - Negotiating contracts (e.g., water transfers)
  - Regulatory compliance

Drought Response Actions

- May 2013 Executive Order on water transfers
- Dec 2013 formation of Governor's Drought Task Force
- Jan 2014 Governor's emergency proclamation
- March 2014 drought relief legislation
- April 2014 proclamation of continued state of emergency
- Sep 2014 Executive Order for emergency drinking water assistance
- Dec 2014 Executive Order continuing CEQA waiver for specified actions
- March 2015 drought relief legislation
- April 2015 Executive Order

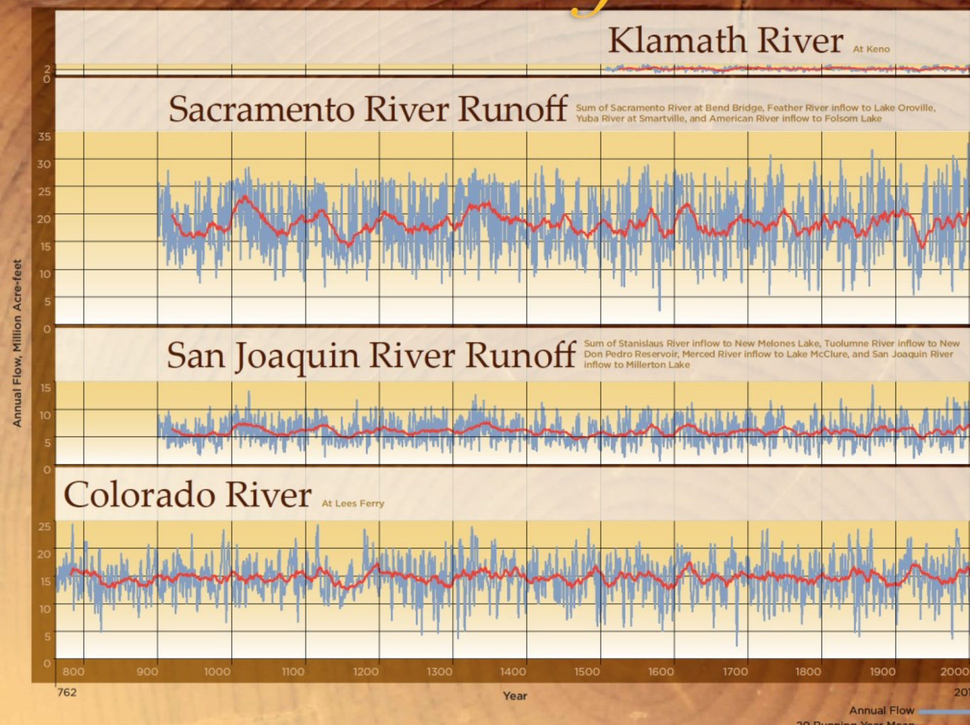
Sample 2015 Drought Activities

- State Water Project/Central Valley Project drought contingency plan implementation (water operations & regulatory compliance, including ESA)
- Emergency salinity barrier in Delta
- Emergency assistance for small water systems & private well owners
- SWRCB regulatory actions (urban water conservation, water rights curtailment)
- Ongoing state financial assistance programs
- Social services assistance in drought-affected rural communities
- Impact monitoring (fallowed ag land, Central Valley land subsidence, groundwater levels)
- Ongoing water transfer activities

So Where Do We Go From Here With Improving (Skillful) Forecasting?

- After numerous CDWR science workshops…
  - Statistical forecasts
  - Using the past to inform the future
    - Paleoclimate information (looking for decadal-scale signals, if any)
    - Analog years
  - Forecasts of opportunity
    - Predicting wet to predict dry (atmospheric river storms)

Reconstructed Streamflows & Drought Periods



USING TREE-RINGS TO RECONSTRUCT STREAMFLOW

A tree-ring reconstruction is a set of tree-ring width data that have been calibrated with an instrumental or gaged record of a hydrologic or climatic variable such as annual streamflow or precipitation. The reconstruction, based on a statistical model that describes the relationship between tree growth and the gage record, extends that record back hundreds of years into the past.

Tree growth in dry climates is limited by water availability. Trees that provide the best information about hydroclimatic variability are those particularly sensitive to variations in moisture. These include species such as blue oak, ponderosa pine, Douglas fir, and western juniper, usually growing at lower elevations in sparse stands on dry and rocky sites where soil moisture storage is minimal.

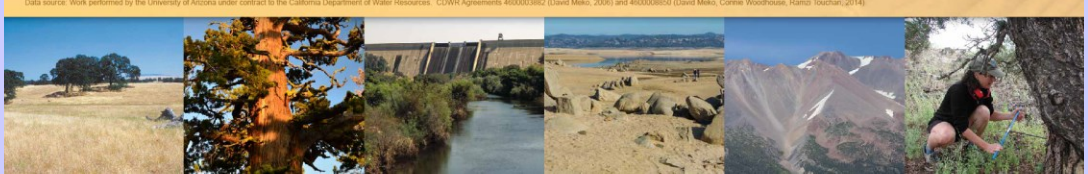
Tree-ring reconstructions of hydroclimatic variables are developed from tree-ring chronologies. A tree-ring chronology is a time-series of annual values derived from the ring-width measurements of 10 or more trees of the same species at a single site. To create a tree-ring chronology, cores from the sampled trees at each site are cross-dated (i.e., patterns of narrow and wide rings are matched from tree to tree) to account for missing or false rings, so that every annual ring is absolutely dated to the correct year. Then all rings are measured to the nearest thousandth of a millimeter using a computer-assisted measuring device. After growth-related trends unrelated to climate are statistically removed, the ring width values from all sampled trees for each year are averaged to create a time series of annual ring width indices. The complete series of ring width indices from a site is called a tree-ring chronology.

Once a gaged record of interest is selected for reconstruction, a set of tree-ring chronologies from the region near the gage is calibrated with the gage record to form a reconstruction model. A statistical technique called multiple linear regression is commonly used. The reconstruction is evaluated by comparing the observed gage values with the reconstructed values by assessing the amount of variance in the gage record that is explained by the reconstruction.

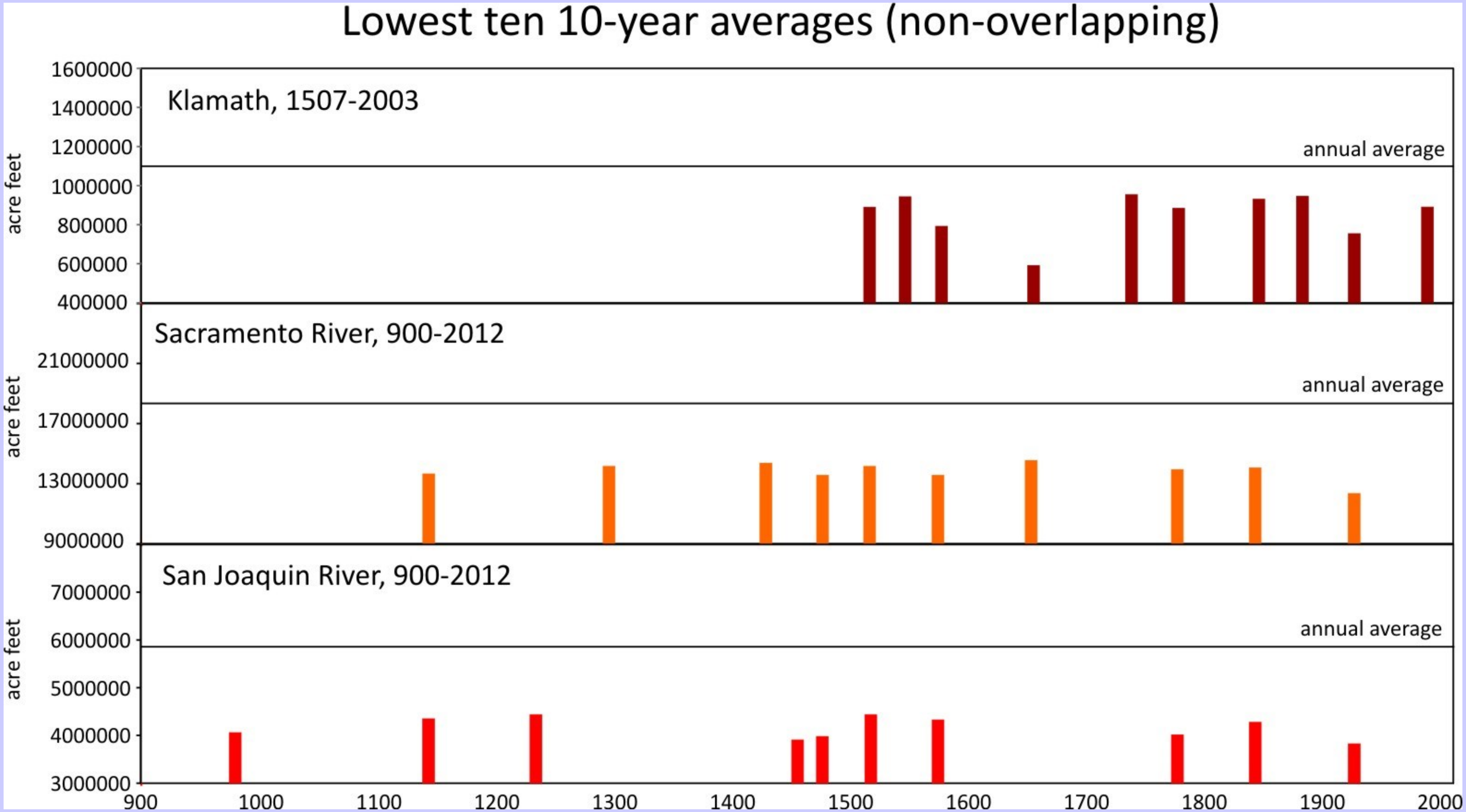
DROUGHTS PRIOR TO THE HISTORICAL RECORD

The period of reliably measured streamflows for rivers throughout the West seldom reaches beyond 100 years, which represents only a fraction of climatologically modern time. As these streamflow reconstructions show, there have been droughts prior to the historical period that were more severe - particularly in duration - than those in the measured record. The reconstructed record captures a broader range of hydrologic variability than does the historical record, making reconstructions useful for drought preparedness planning. Of particular interest from a scientific perspective is the Medieval Climate Anomaly, a time during which sustained severe drought gripped much of the western United States, as exemplified illustrated in the Sacramento, San Joaquin, and Colorado River reconstructions.

Data source: Work performed by the University of Arizona under contract to the California Department of Water Resources. CDWR Agreements 4600003882 (David Meko, 2006) and 4600008850 (David Meko, Connie Woodhouse, Ramzi Touchan, 2014)



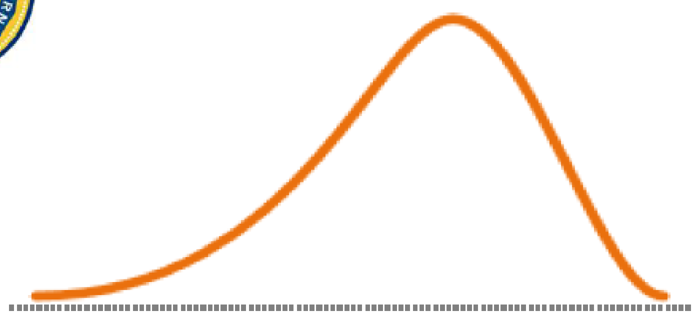
Big Benefit – Understanding Drought Risk



Courtesy of Connie Woodhouse

One Approach -- Analog Years & Statistical Modeling

Drought Prediction



$f\,(Precip\,|\,?\,)$

Using Bayesian network…

$$f(x|y,z,\ldots) \propto f(x,y,z,\ldots)$$

We apply *Copula functions* to determine the joint and conditional probabilities [f(x,y,z), f(x|y,z)]

- Large-scale climate signals
  - Southern Oscillation Index (SOI)
  - Pacific Decadal Oscillation (PDO)
  - Multivariate ENSO Index (MEI)
  - Arctic Oscillation (AO)
- Local-scale climate signals
  - Near-past condition (e.g. SPI)
- Combination of Large-/Local-scale signals
- What else?

Let's try

- SOI
- (SOI , PDO)
- (PDO , MEI)
- (SOI , SPI)
- (PDO, SOI, SPI)

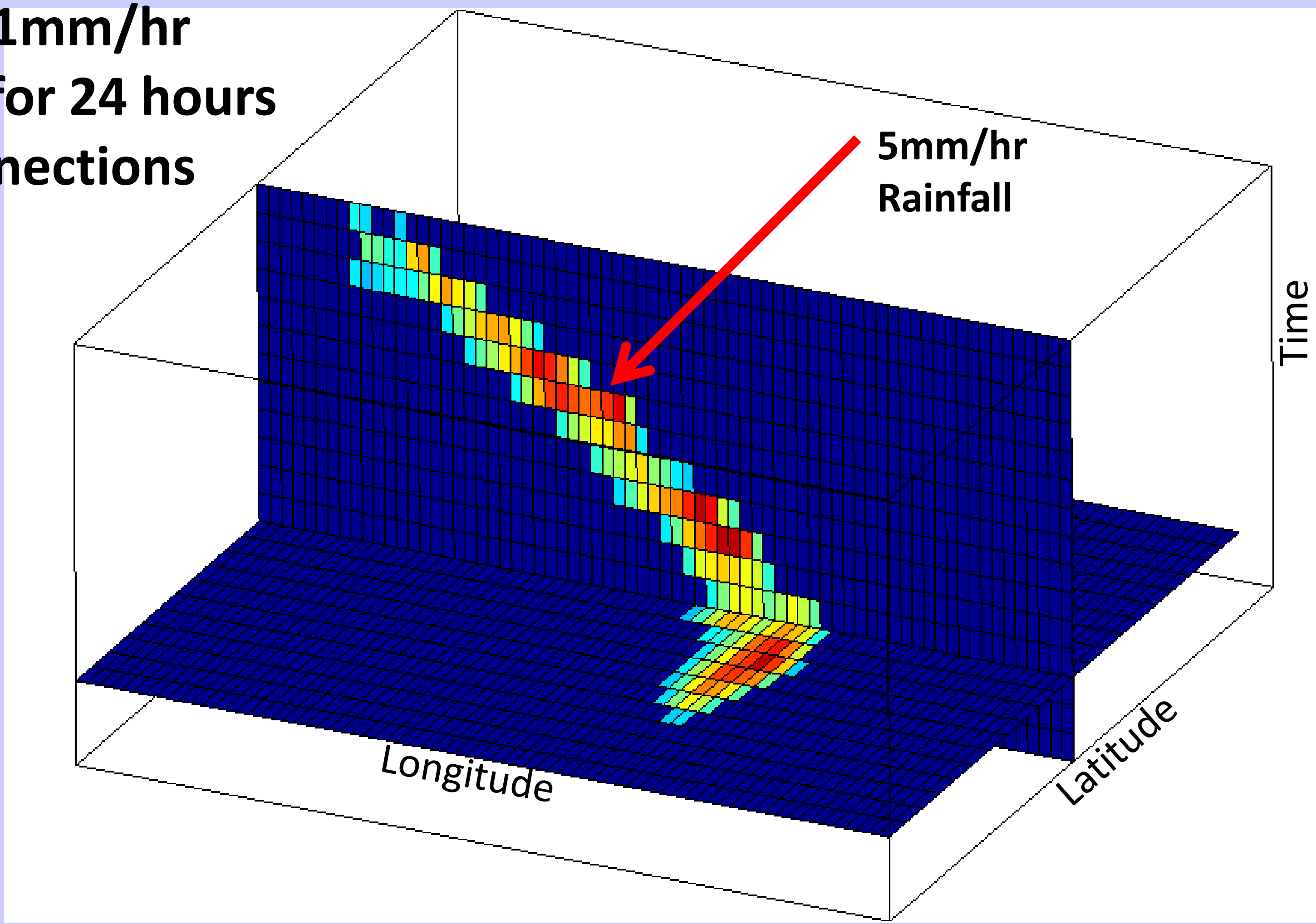
Another Approach – Predicting Atmospheric River Storms

- Can we predict ARs or conditions favorable for their formation?
- Can we link AR formation to synoptic climate conditions?
- Can we link ARs to snowpack?
- (Does the absence of ARs signal a bias toward dry conditions?)

4D: "Synthetic" Precipitation Object

CONNECT algorithm criteria:

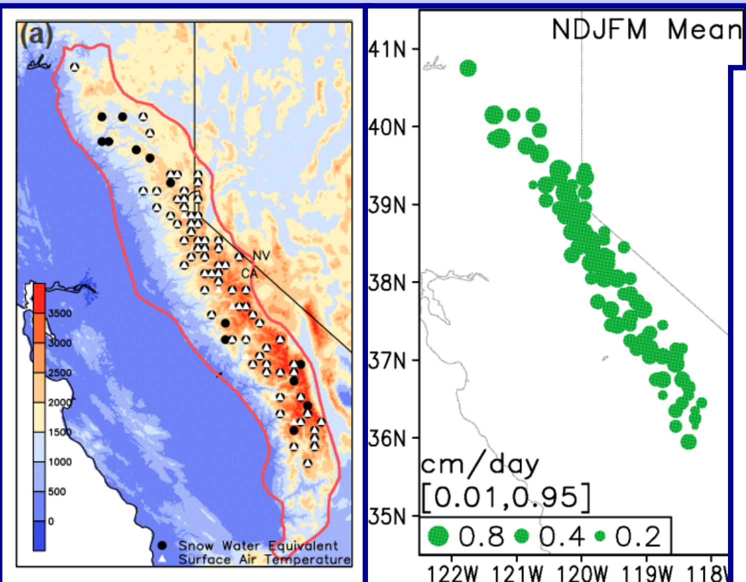
1) Must have 1mm/hr
2) Must exist for 24 hours
3) 6 voxel connections

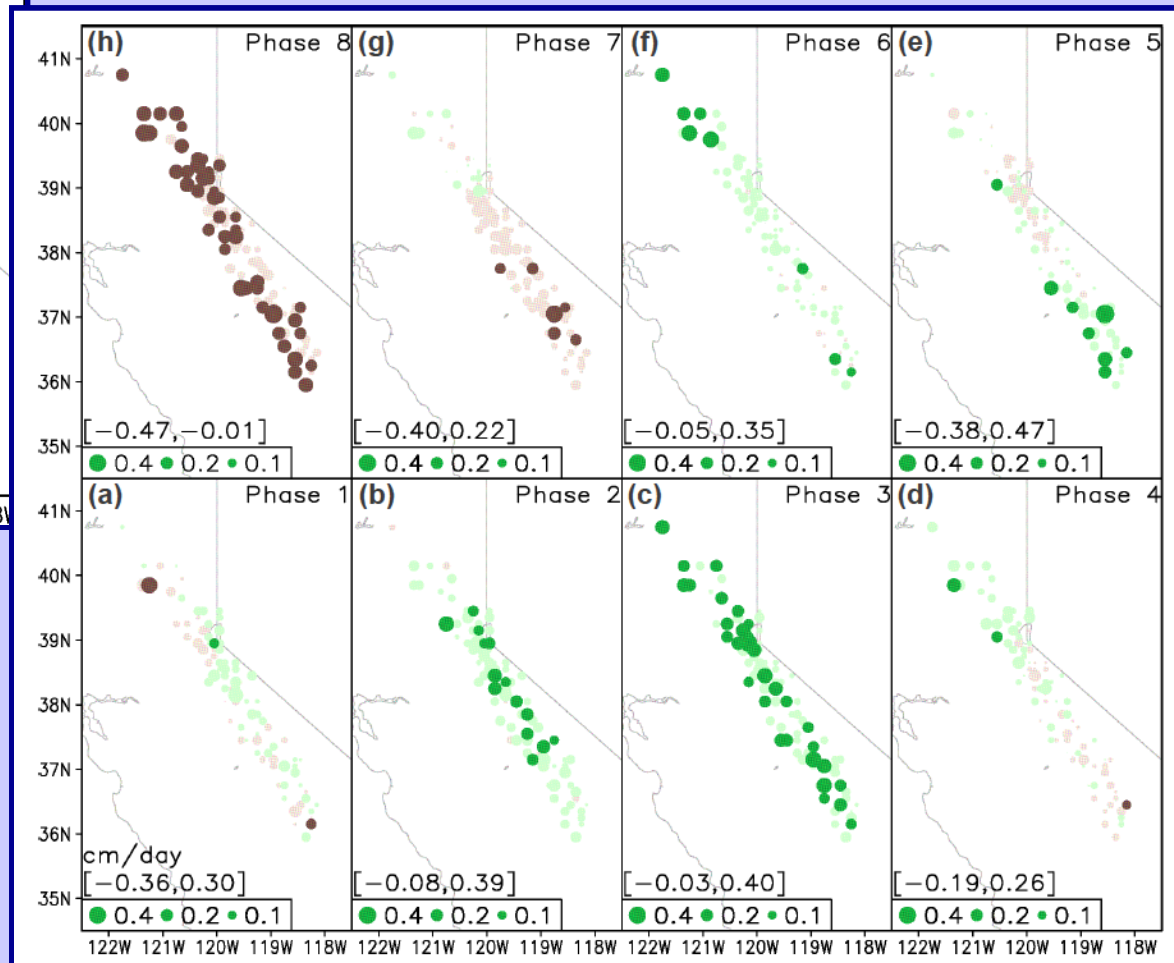


Courtesy of UC Irvine

MJO Influence on Sierra Snowpack

- Snowpack in the Sierra acts as a natural and important reservoir for CA.
- Snowfall often comes in powerful winter storms, sometimes with Atmospheric Rivers (not shown).





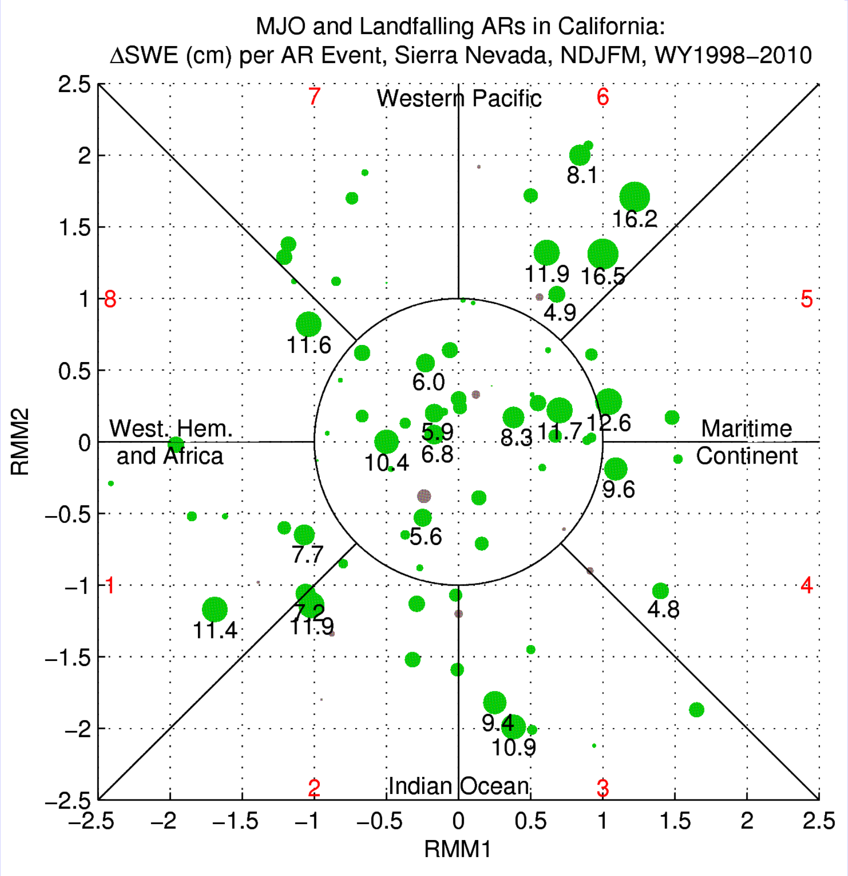
- The Madden Julian Oscillation appears to impart a strong (~40%) modulation of snowfall rates (and Air T; not shown).
- MJO Phase 3 -> + 30-50%
- MJO Phase 8 -> - 30-50%

Implies Valuable Predictability

Guan, B., D. E. Waliser, N. Molotch, E. Fetzer, P. Neiman, 2012: Does the Madden-Julian Oscillation Influence Wintertime Atmospheric Rivers and Snowpack in the Sierra Nevada?, Mon. Wea. Rev., 140, 325–342,

Does the MJO Influence Atmospheric Rivers Timing or Frequency?

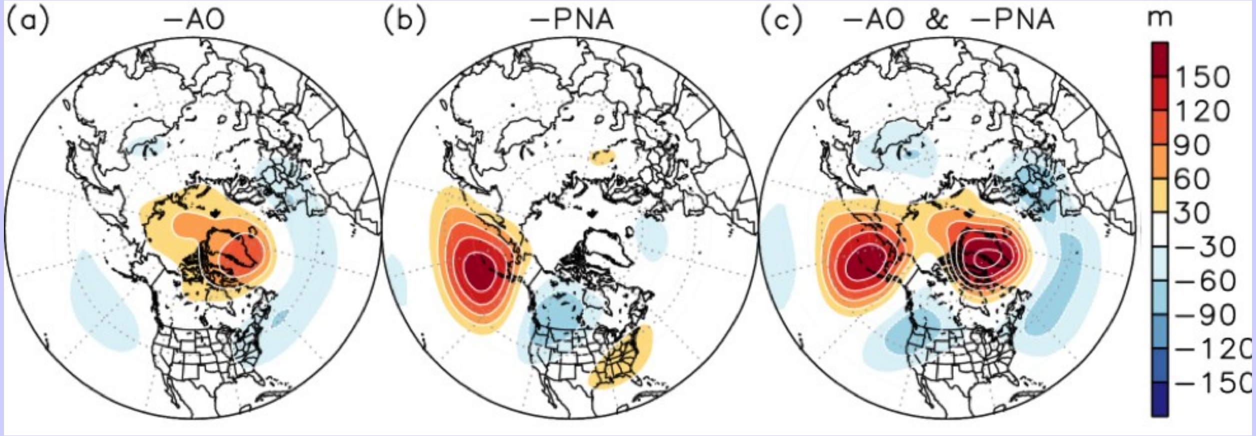
AR events during WY 1998-2010 are plotted in relation to the phase and amplitude of the MJO. The amplitude of the AR is shown in terms of ∆SWE as size of green circles. AR dots/events inside the unit circle occur during weak/no MJO. AR dots/events outside unit circle occur during strong MJO events in the given phase of the MJO life-cycle.



More high-impact ARs are observed during MJO phase 6 – convection in the W. Pacific Ocean, including the top two events during WY1998-2010

Guan, B., D. E. Waliser, N. Molotch, E. Fetzer, P. Neiman, 2012: Does the Madden-Julian Oscillation Influence Wintertime Atmospheric Rivers and Snowpack in the Sierra Nevada?, Mon. Wea. Rev., 140, 325–342,

Potential for Improvements in Long-Range Forecasts

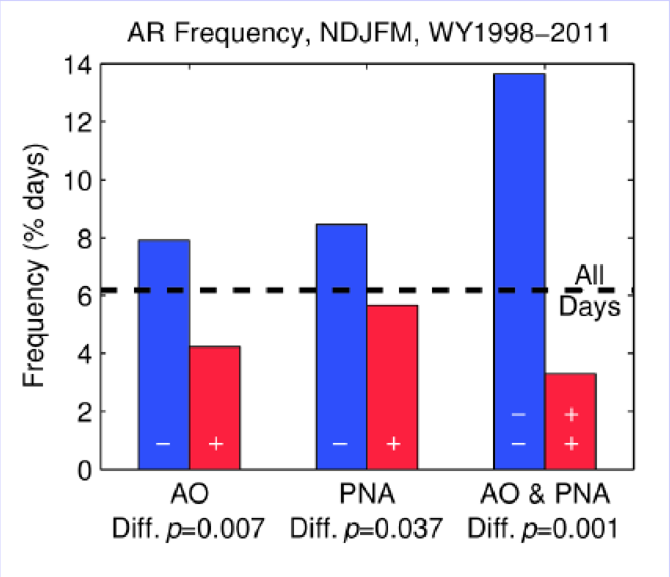


500 mb Geopotential Height Anomalies

"Arctic Oscillation" (AO)

"Pacific North American" (PNA)

Circulation anomaly when both PNA and AO in "negative" phase



- On average 6-7 Atmospheric River (AR) events provided 30-40% of total seasonal snow water equivalent (SWE) accumulation in most years
- When PNA & AO are in "negative" phases, there is a doubling of the frequency of ARs
- Since PNA & AO exhibit some predictability from days to months, it may be possible to extend forecasts of ARs

B. Guan, N. P. Molotch, D. E. Waliser, E. J. Fetzer, and P. J. Neiman, 2013, *Water Resources Review*, Minor Revisions

Outcomes of CDWR’s Work to Date

- Paleoclimate reconstructions very helpful for providing context for drought risk
- Statistical forecasts may prove useful
- “Low-hanging fruit” potential from use of historical records, analog years for scenario planning
- Further research on predictability associated with ARs appears promising

Current CDWR-Funded Research

- Developing databases of AR storms/synoptic climate, object-oriented satellite precip database (2 projects, UCI & UCSD)
- Analog years database and statistical model (UCI)
- Paleoclimate reconstructions of Southern California streamflow/precip (in contract, U of AZ)
- AR/MJO predictions (in contract, JPL/UCLA)