Climate Change and CVP

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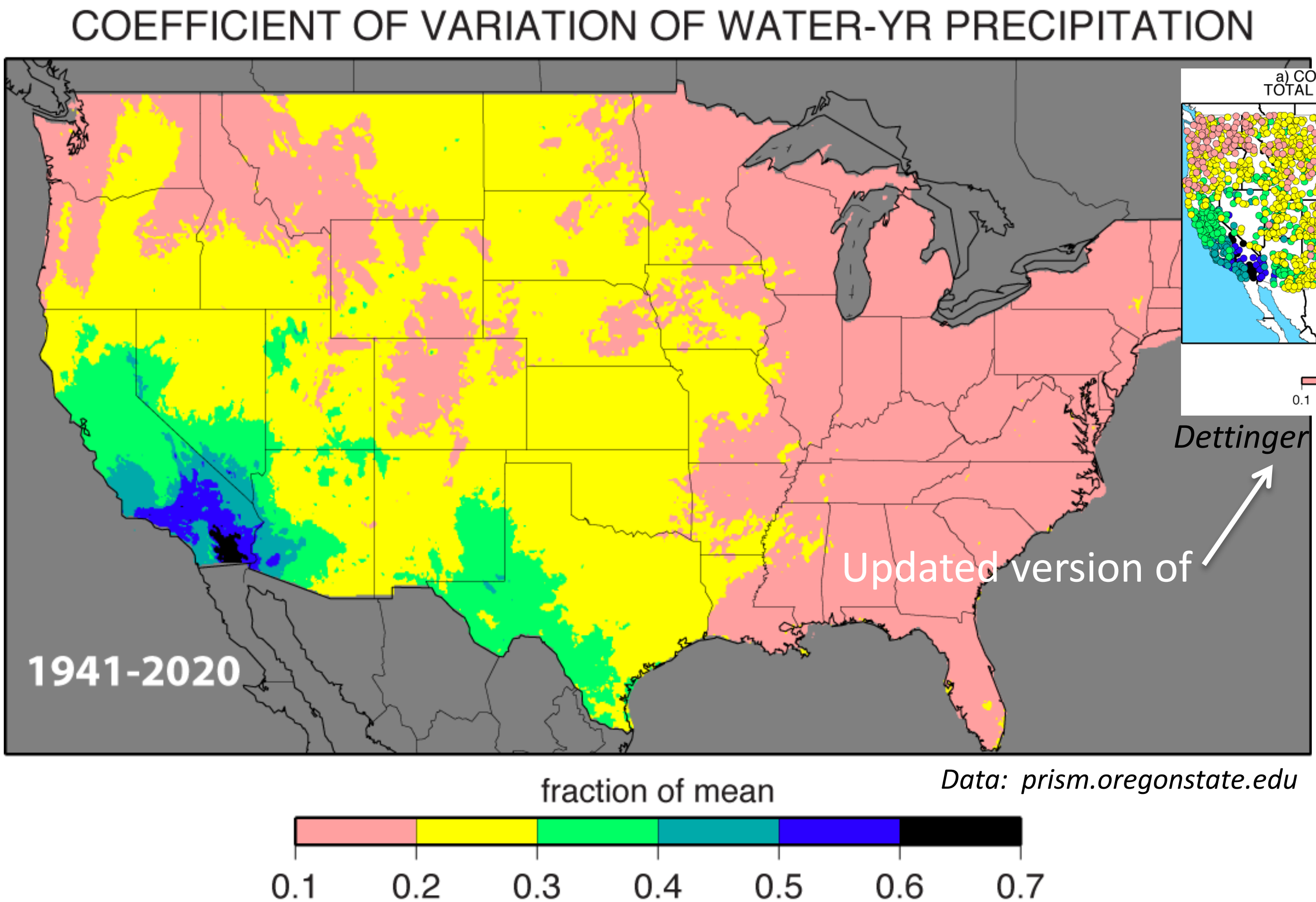
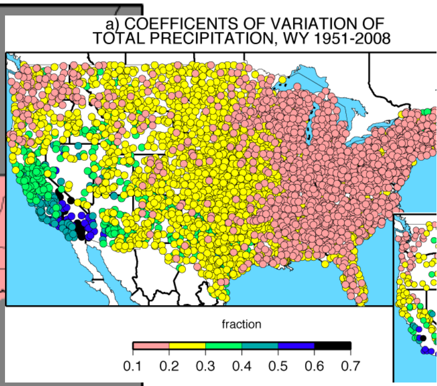
1. California has an EXTREMELY Variable Precipitation Regime

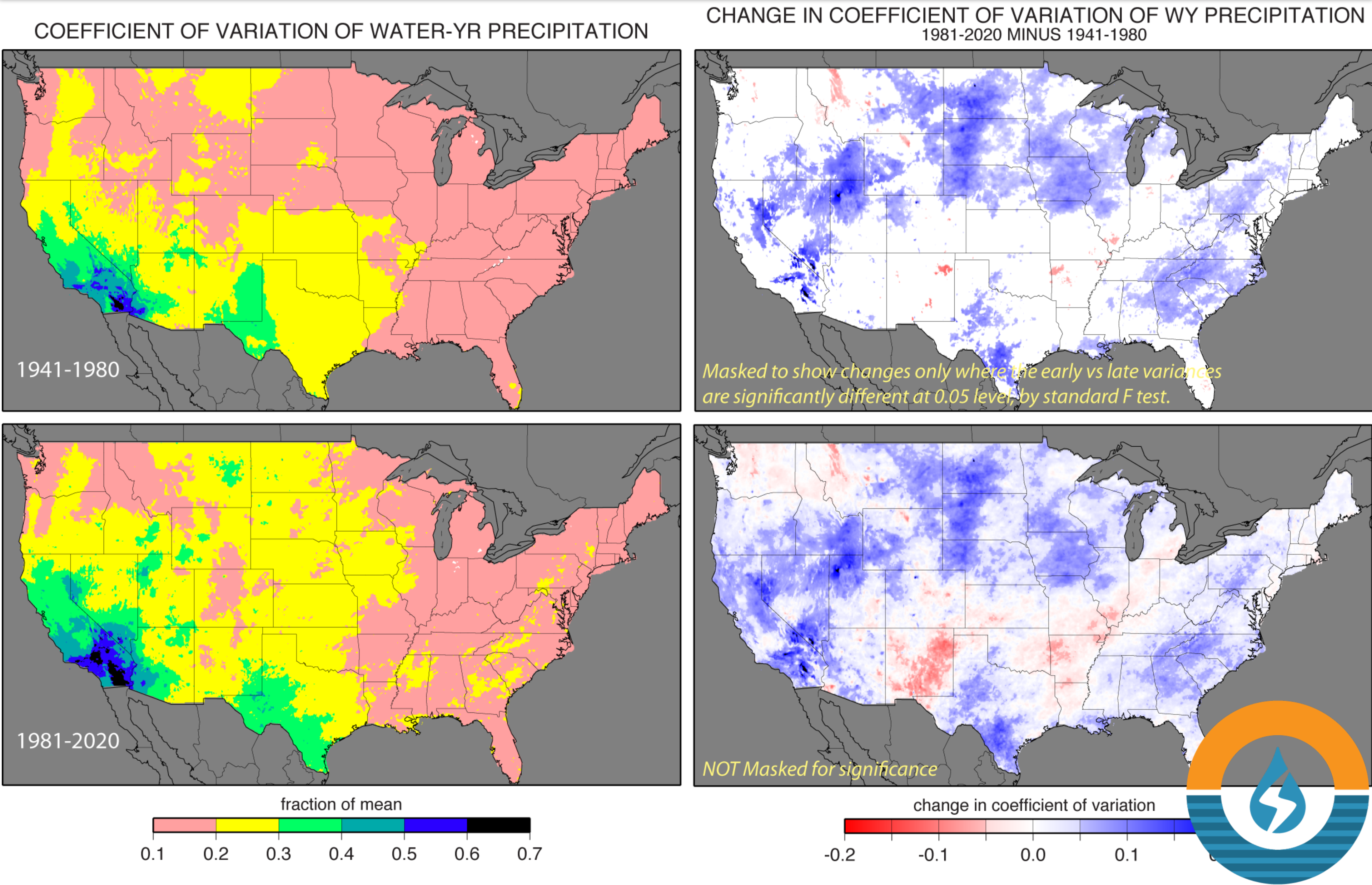




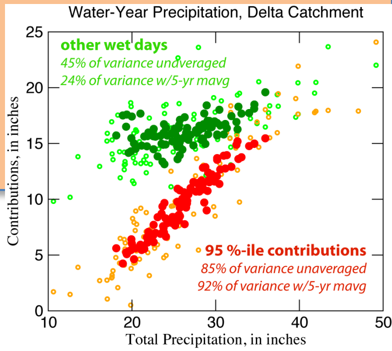
Dettinger et al., Water, 2011

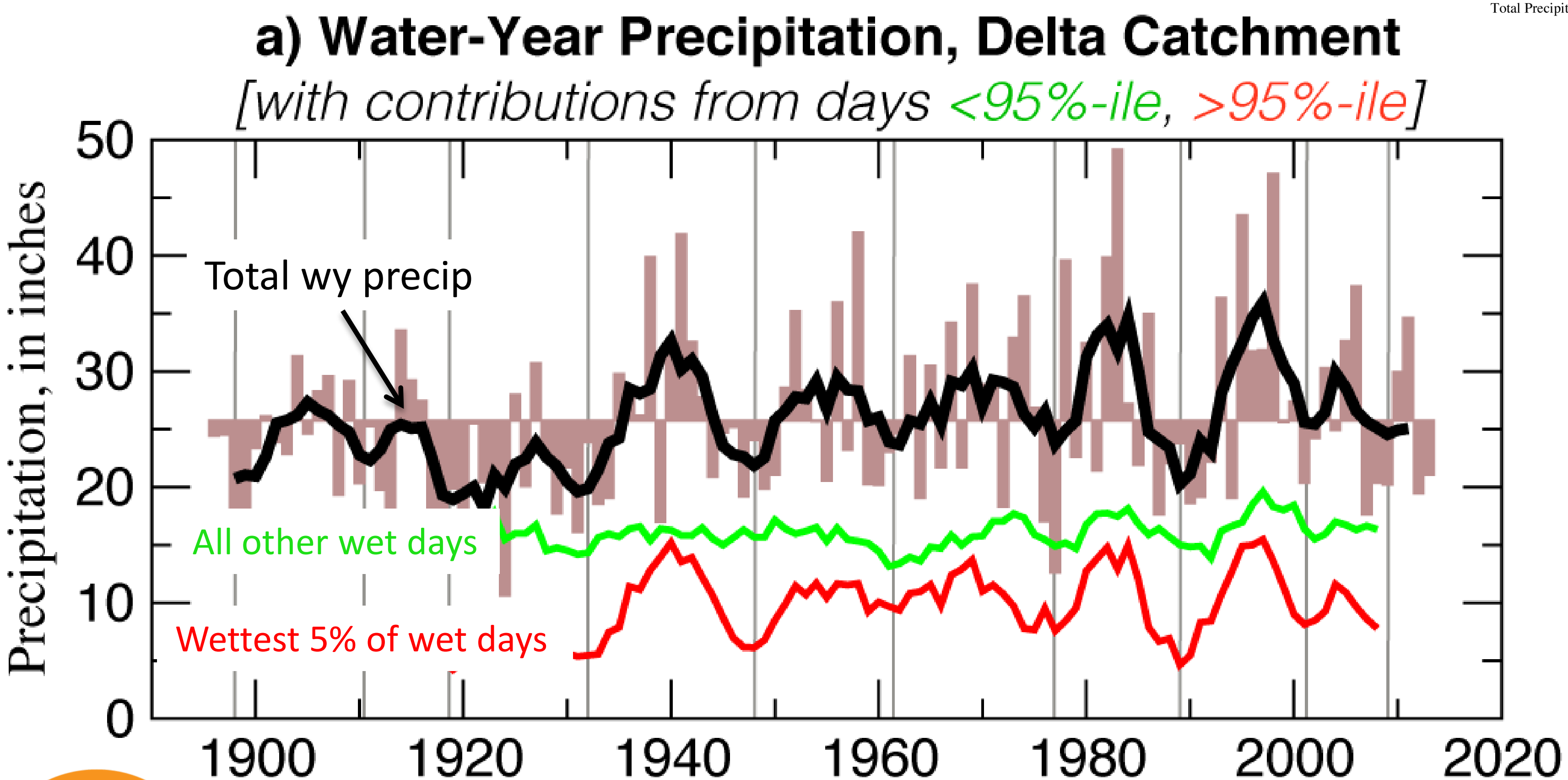
Data: prism.oregonstate.edu

1b. … and its getting even MORE EXTREME.



1c. California's floods and droughts are BOTH driven by its largest storms

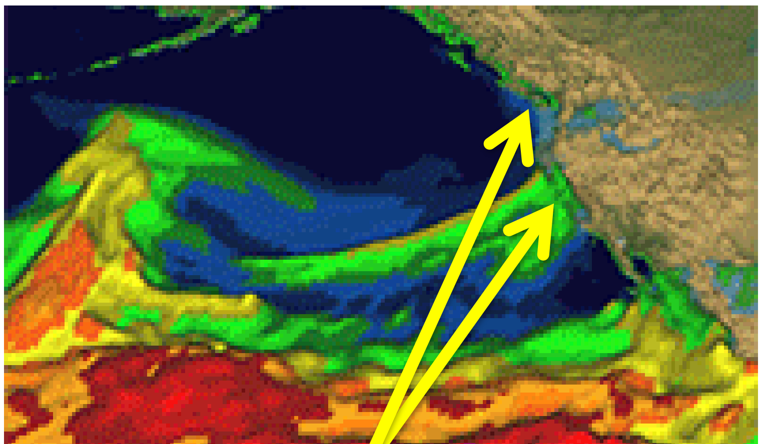




Dettinger & Cayan, SFEWS, 2014;
Dettinger, SFEWS, 2016

1d. Climate change will bring enhancements of our largest storms, while weakening "other storms" & adding dry days

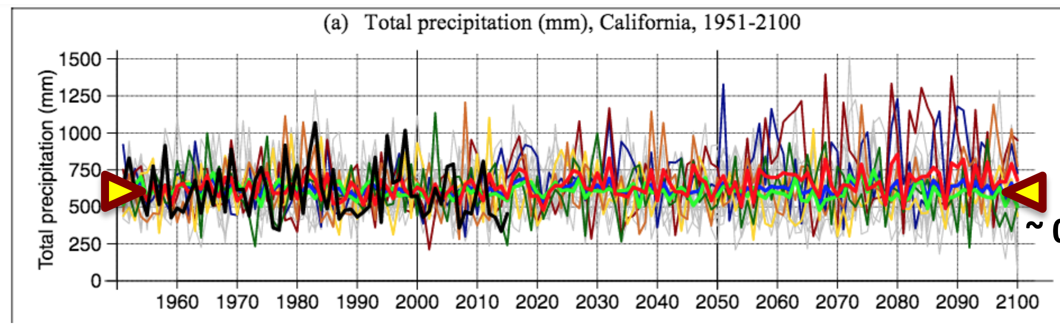
Water Vapor Transports (warmest colors) during 3 weeks in winter 2010



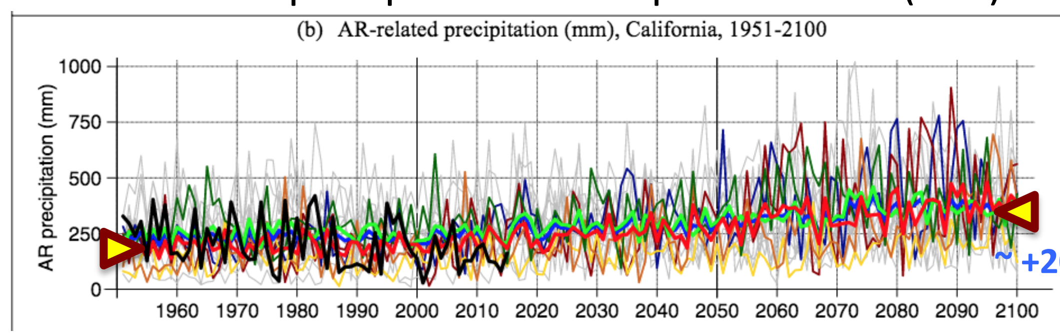
Landfalling atmospheric rivers

→ Big AR storms get bigger; other storms get fewer & farther between.

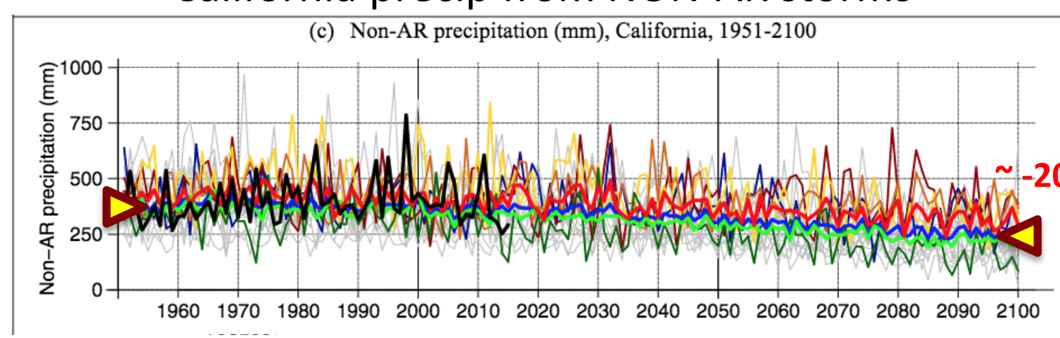
TOTAL California precip



California precip from Atmospheric Rivers(ARs)



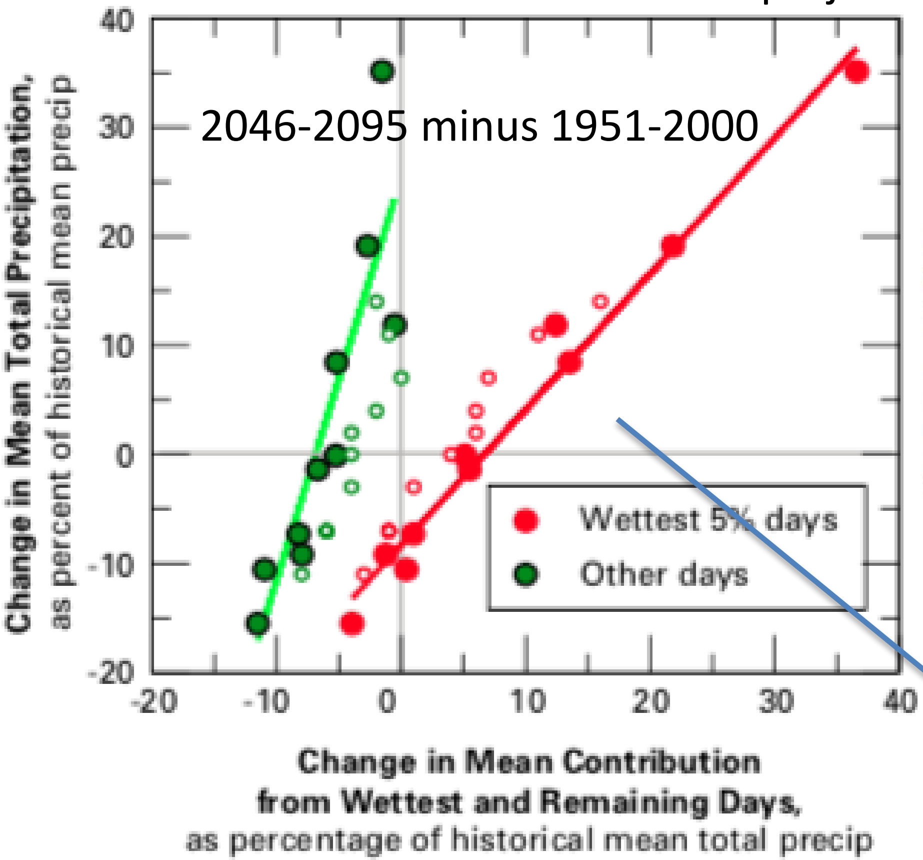
California precip from NON-AR storms



Gershunov et al., SciRpts, 2019; Polade et al., SciRpts, 2014

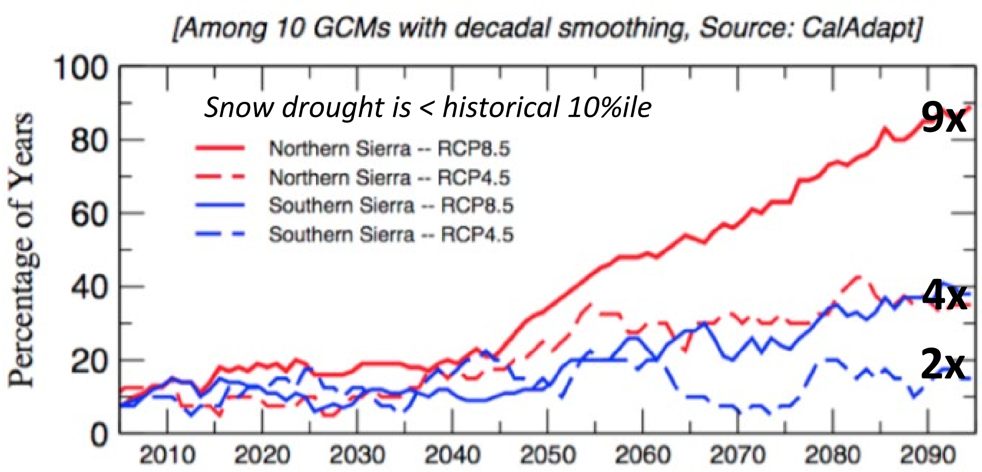
1e. California's future floods & droughts will also be even wilder

Contributions to total water-yr precip
from extreme storms vs "normal" storms
in a 10-model ensemble of climate projections



Dettinger, SFEWS, 2016

SNOW DROUGHTS/decade

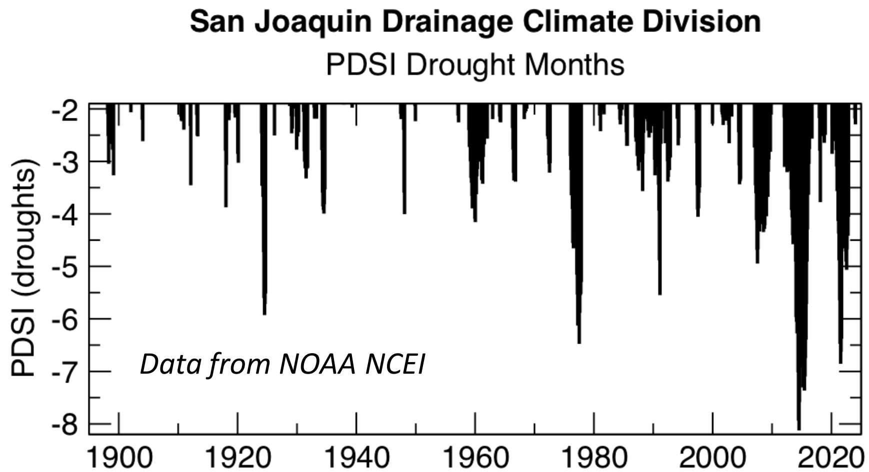


Dettinger et al., CCC4A, 2018

20 of 20 projections yield smaller "other storm" contributions
16 of 20 projections yield larger extreme-storm contributions

2. California droughts have been intensifying over the past few decades

Palmer Drought Severity Index
(droughts only shown)

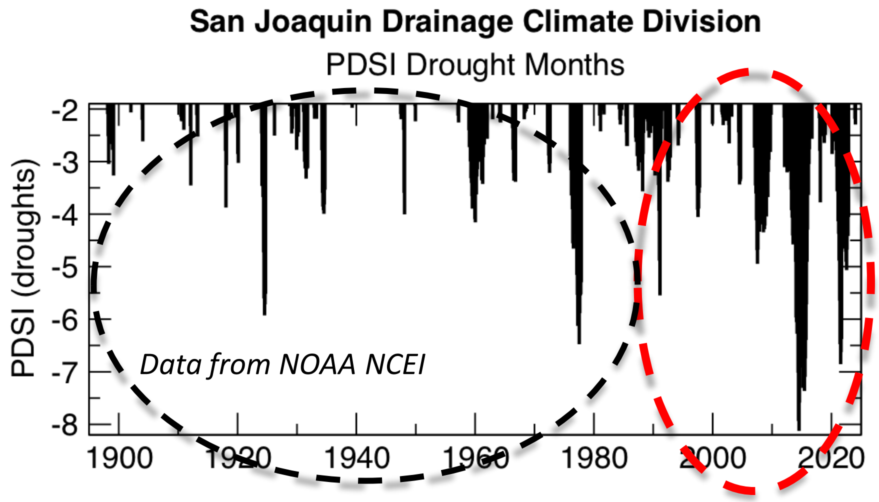


PDSI: -2 to -3, moderate drought
-3 to -4, severe drought
< -4, extreme drought

2b. …largely because California's evaporative demand is increasing as temperatures rise

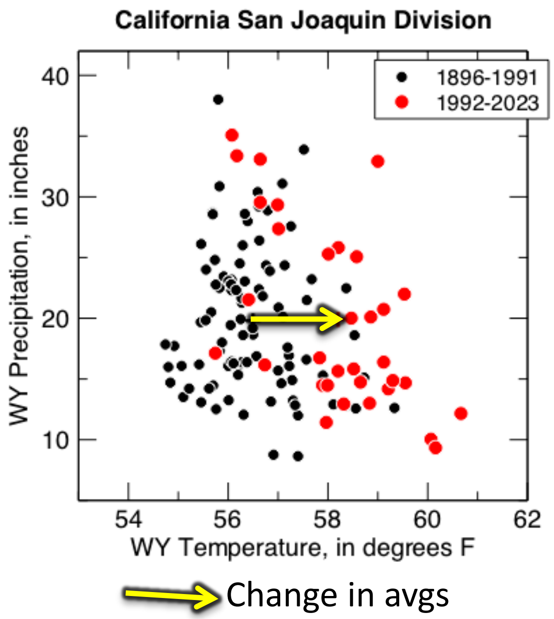
Palmer Drought Severity Index

Is a function of monthly precip & temperature



PDSI: -2 to -3, moderate drought
-3 to -4, severe drought
< -4, extreme drought

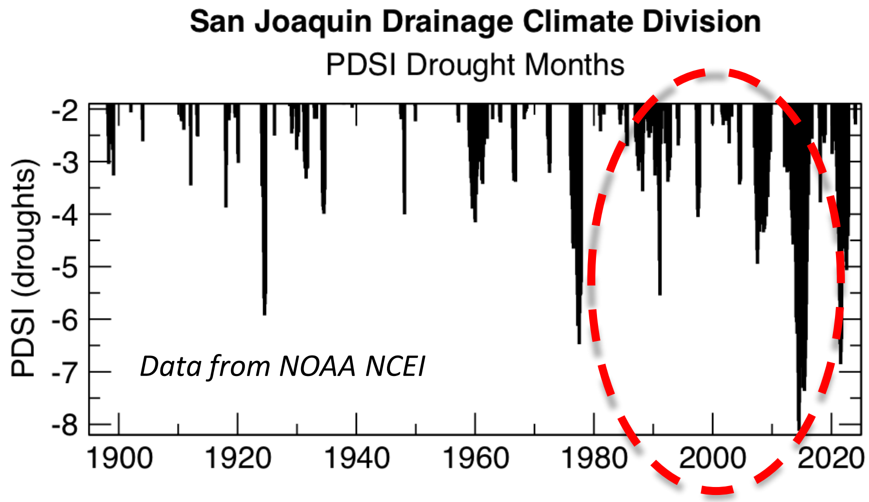
Atmospheric evaporative demand is how much evapotranspiration would occur from well-water lawn (as measured at CMIS stations)



Almost no change in average precip, but ~ +2^{o}F warming

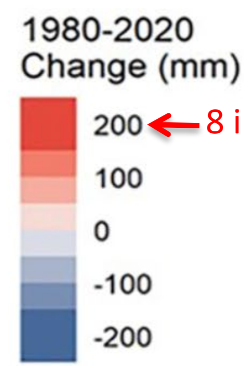
2c. More broadly, California's (& much of the Nation's) evaporative demand has increased over the past 40 yrs

Palmer Drought Severity Index



PDSI: -2 to -3, moderate drought
-3 to -4, severe drought
< -4, extreme drought

Observed Change in Atmospheric Evaporative Demand (ETo), 1980-2020, in five modern datasets



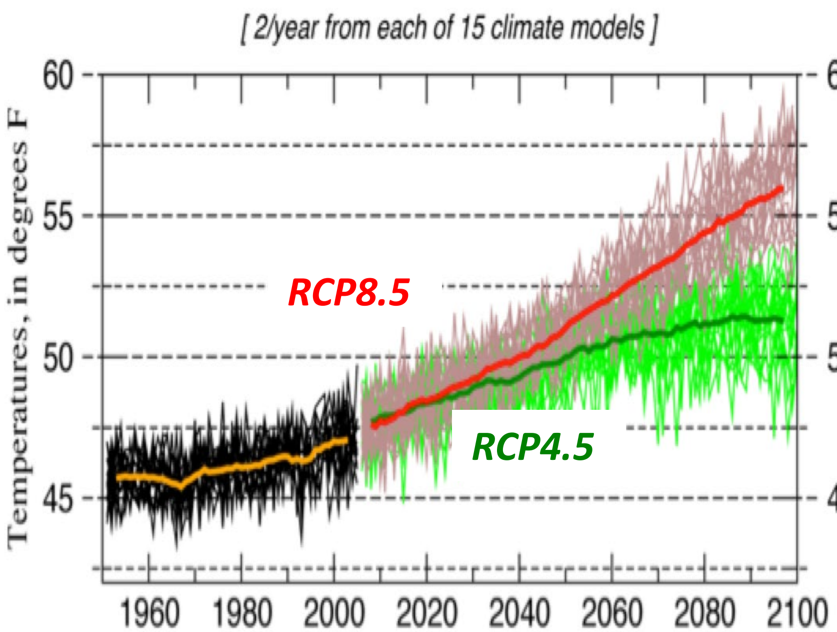
8 inches more demand

Albano et al., JHM, 2022

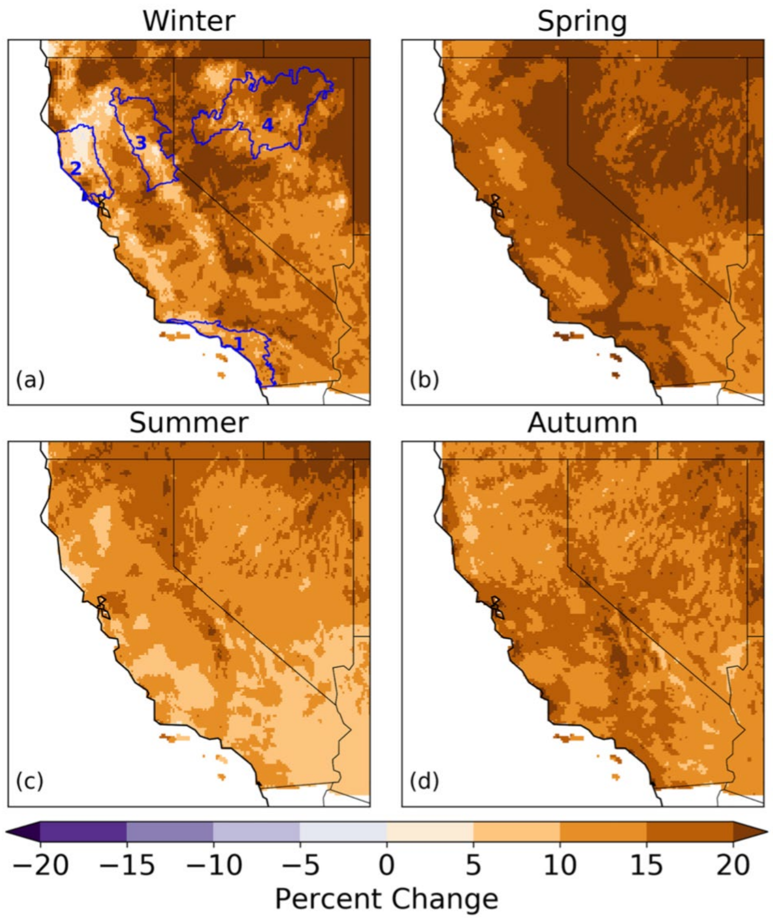
Note: ETo is reference atmospheric demand for water (what is measured at CMIS stations), a function of temperature, humidity, sunshine, & wind, but not precip.

2d. …and more warmth & ETo are on their way

Projected Annual Air-Temperatures, Northern Sierra Nevada



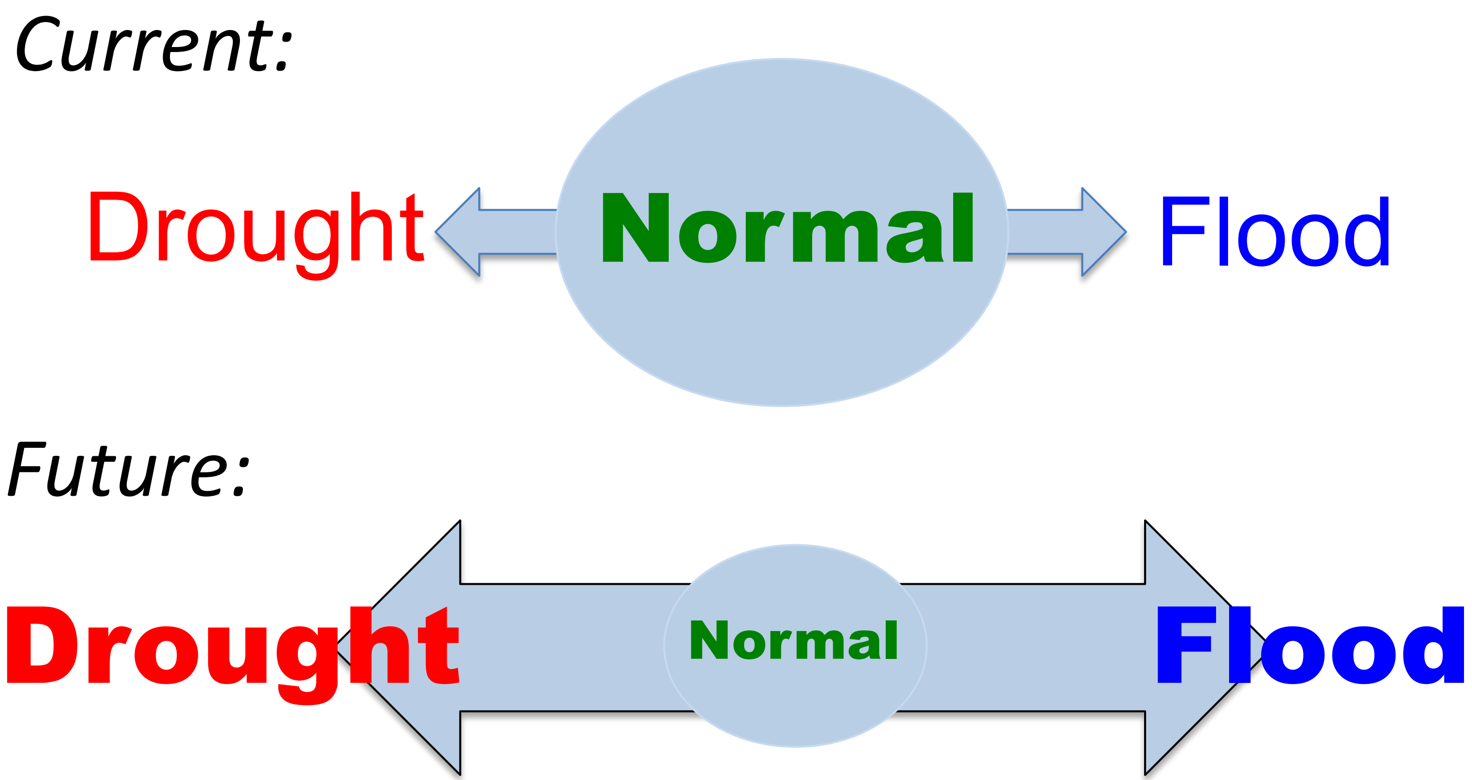
RCP8.5 Seven-GCM-Ensemble-Mean Projected Changes in ETo, by 2070-2099



Note: ETo is reference atmospheric demand for water (what is measured at CMIS stations)

McEvoy et al., Earths Future, 2020

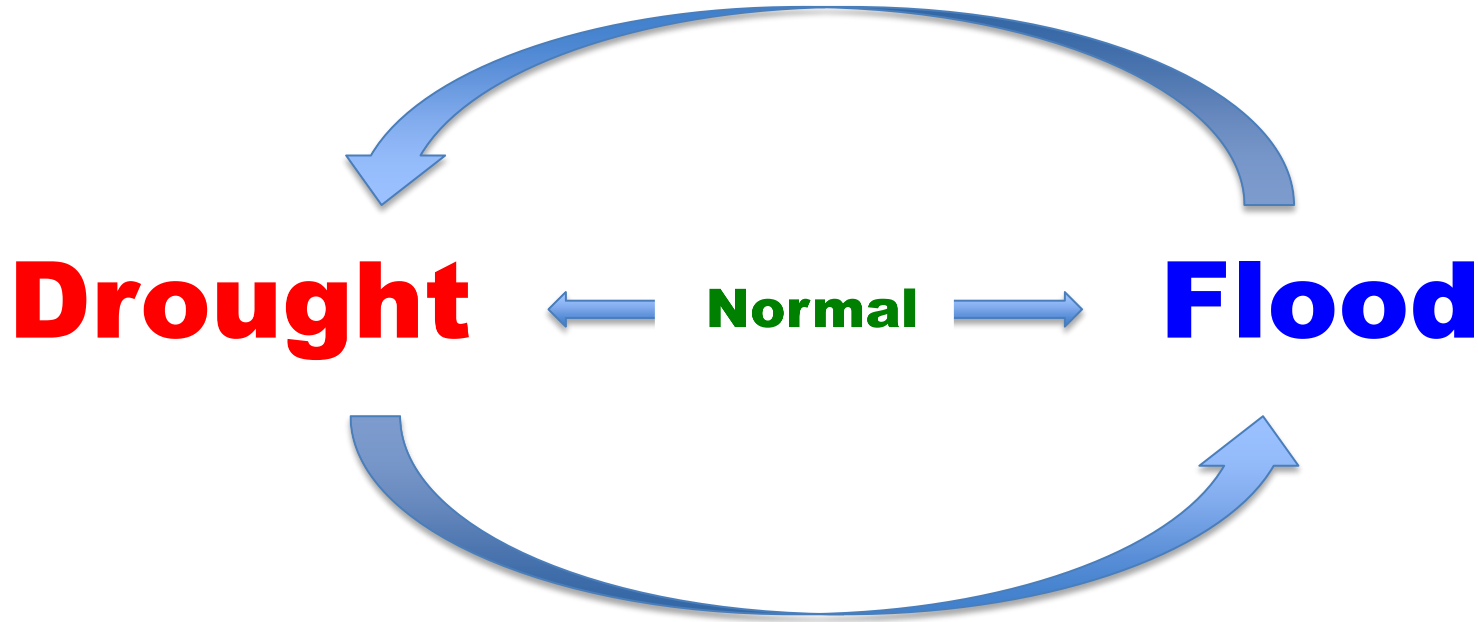
3a. California's water resources will have to rely more on capturing extremes *(water from floods, storage space from drought)*



Dettinger, DWR Planning4Change, 2019

FIRO?

3a. California will increasingly need to manage its floods to get thru its droughts, and vice versa



- Floods will be constitute greater fraction of the water availability; HOW ARE WE GOING TO KEEP THAT WATER IN THE MIX?
- CAN DROUGHT BE BETTER MANAGED TO CREATE SPACE FOR CAPTURING FLOODS TO COME OR REDUCING LONG-TERM DEMANDS?

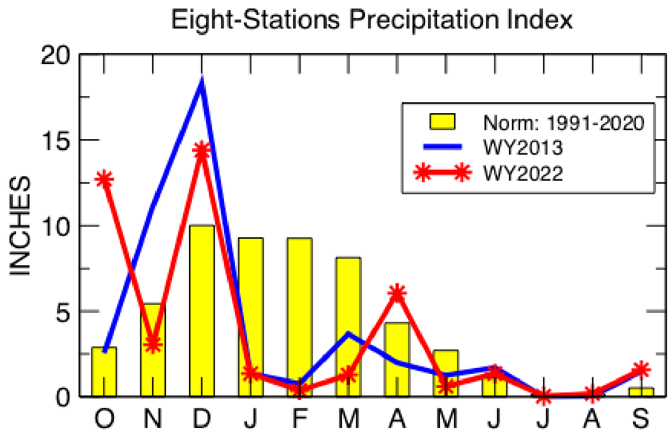
FIRO-MAR?

Dettinger, DWR Planning4Change, 2019

3b. Increased variability will be ever more challenging in a system pushed toward its limits

Current regulations have significant "climate basis," but climate variability/seasonality may change

E.g., in WY 2013 & 2022, most precipitation arrived in autumn followed by really dry winters…& yet regulatory decisions mostly reflected "really wet year to date" to a dangerous extent

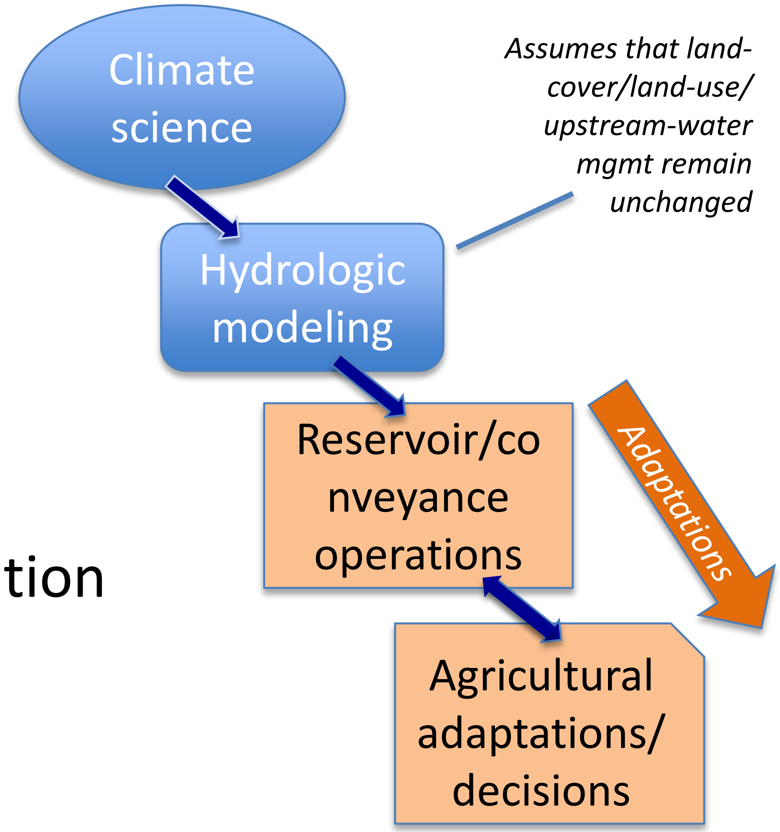


Should regulatory framework be more flexible *(perhaps even forecast-informed)* to accommodate a California with **INCREASING WITHIN-YEAR & YEAR-TO-YEAR VARIABILITY**?

VERO? (Variability-Enhanced Regulatory Options?)

3c. Climate-change impacts on CVP are not written in stone

Climate-change projections used for most planning *(e.g., CalAdapt)* assume land cover & land use (the physical-hydrologic setting) remains unchanged, with water–availability changes dictated only by large-scale climate



California leads the world wrt GHG mitigation & adaptations for projected water-supply changes

Should California ALSO ACTIVELY STRIVE TO STABILIZE HYDROLOGIC CONDITIONS in its watersheds?

See Dettinger et al., SFEWS, 2023

OBSERVATIONS

-- California's precipitation & hydrology is getting more extreme (& will continue to do so)

-- Evaporative demands are increasing (& will continue to do so)

RESPONSES

-- Management of water resources will increasingly be about SALVAGING/USING the extremes

-- More flexible *(& perhaps even forecast-informed?)* **regulatory/allocation decisions will be needed to address more S2A-variable hydroclimate**

-- Options exist for REDUCING hydrologic impacts by aggressive on-the-ground action in the watersheds

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Comments or questions?

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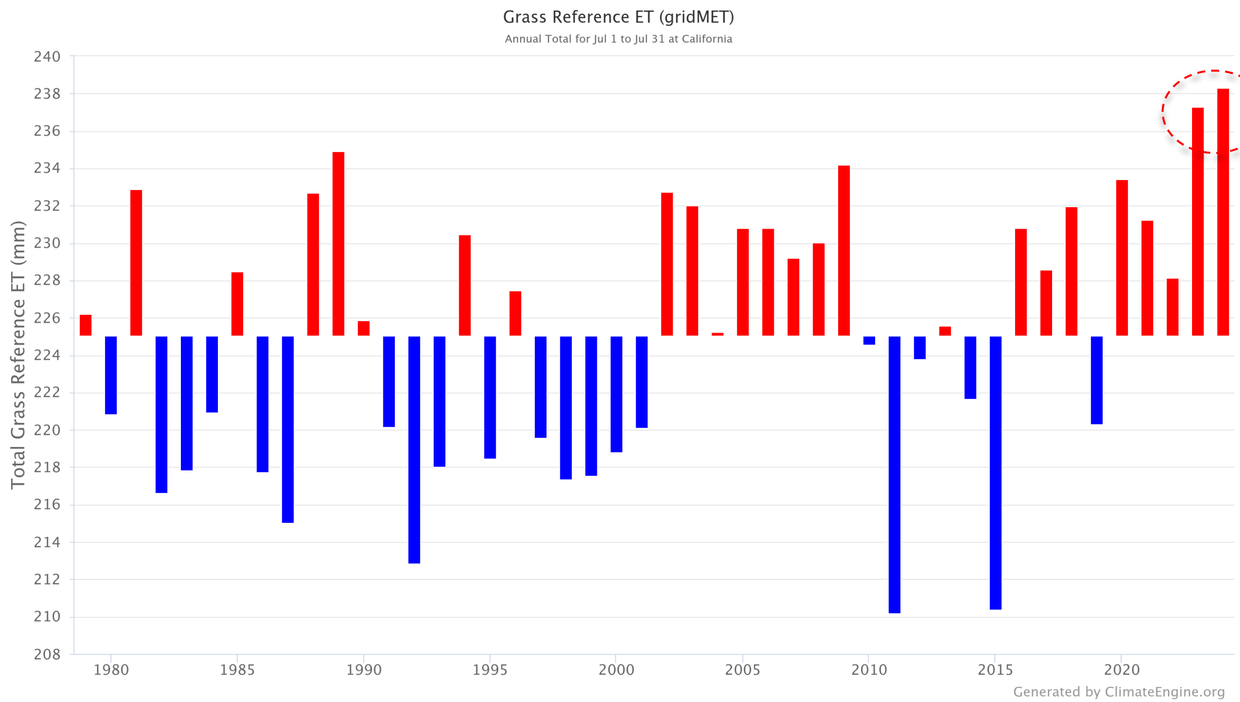
2e. FWIW, this summer & last summer are pretty good examples of how near-future of intense-r demands may feel

California-state average July Evaporative Demands (as ETo)



Provided by Dan McEvoy, DRI/WRCC

Projected *(in 2011 & 2024)* water temperatures at Rio Vista in the Delta

Estuaries and Coasts

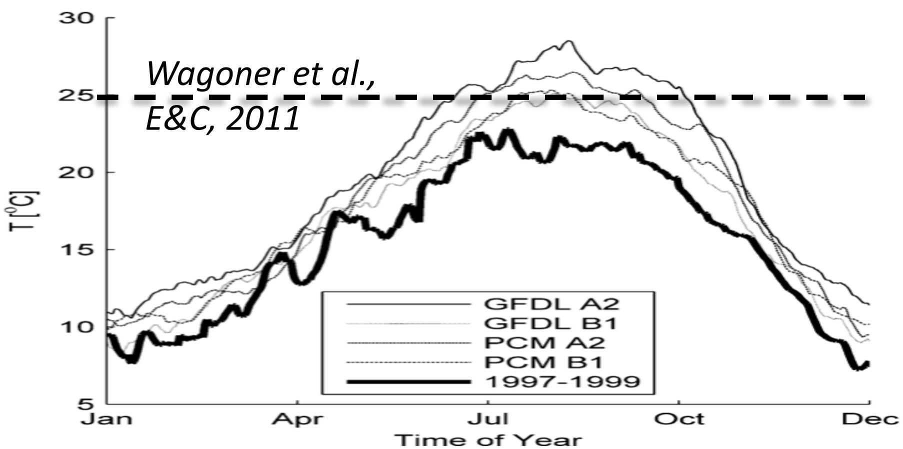
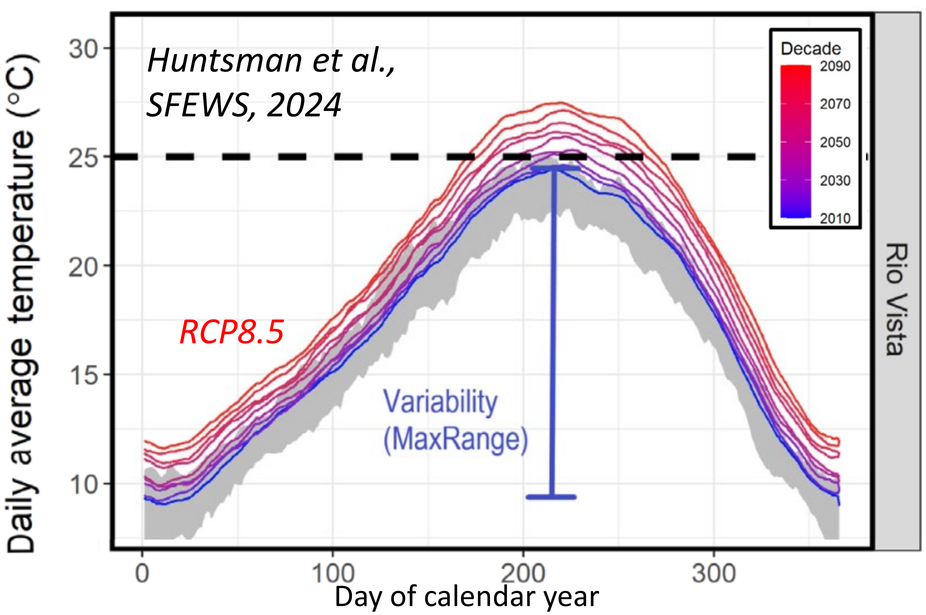


Fig. 11 Projected yearly cycle of water temperatures at Sacramento River at Rio Vista (station 15) averaged from 2097 to 2099. The mean of the measured water temperatures at the same location from 1997 to 1999 is included for comparison



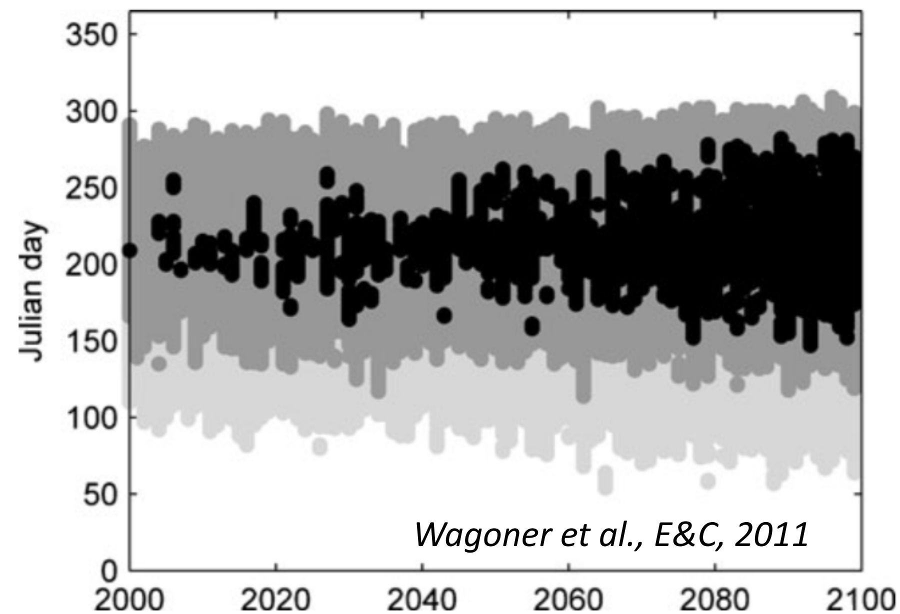
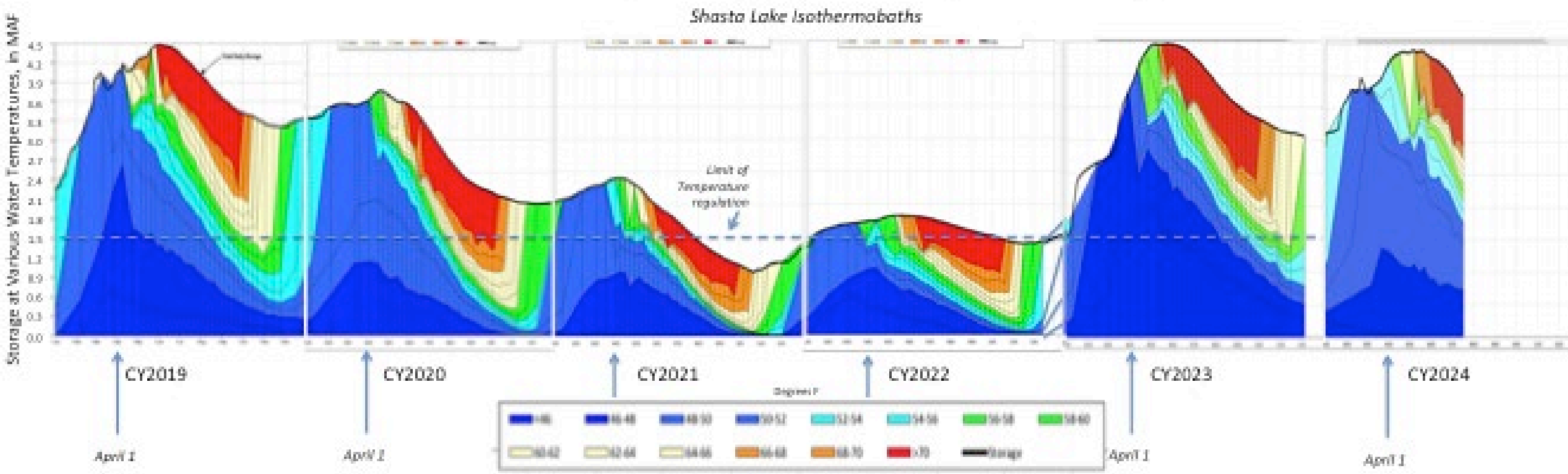


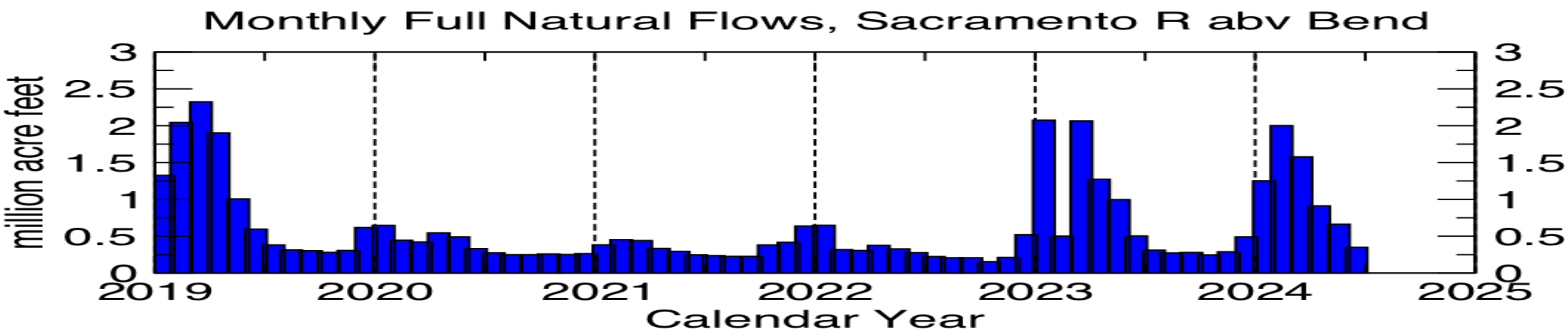
Fig. 13 Long-term shift in water temperatures on the Sacramento River at Rio Vista (station 15) under GFDL A2 forcing. Using projected temperatures, each day is grouped as it impacts the Delta smelt: spring spawning (daily average temperatures from 15°C to 20° C in *light gray*), stress (daily average temperatures from 20°C to 25°C in *dark gray*), and lethal (daily maximum temperatures >25°C in *black*)

Cold-Water Drought in Lake Shasta

Here is how water temperatures & volumes in Lake Shasta have evolved (with depth) over the past several yrs.



Data source: *https://www.usbr.gov/mp/cvo/temperature.html*



Projected annual air temperatures & precipitation

Temperature Change

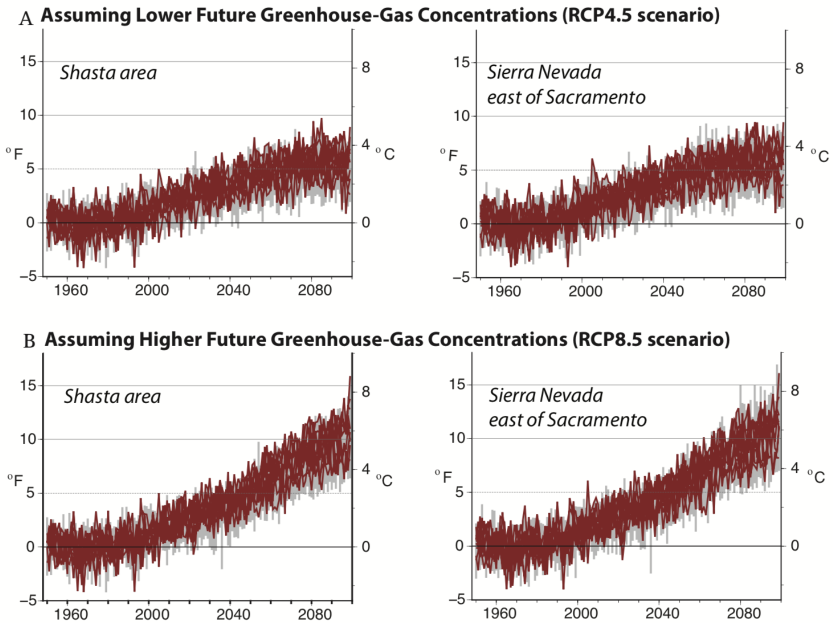


Figure 2 Projected annual changes in air temperature, relative to 1961–1990 averages, in 10 selected global climate models (bright curves, 5-year moving averaged) and in 31 models (grey, unsmoothed), under low **(A)** and high **(B)** future greenhouse-gas emissions. (Source: CDWR Climate Change Technical Advisory Group 2015).

Precipitation Change

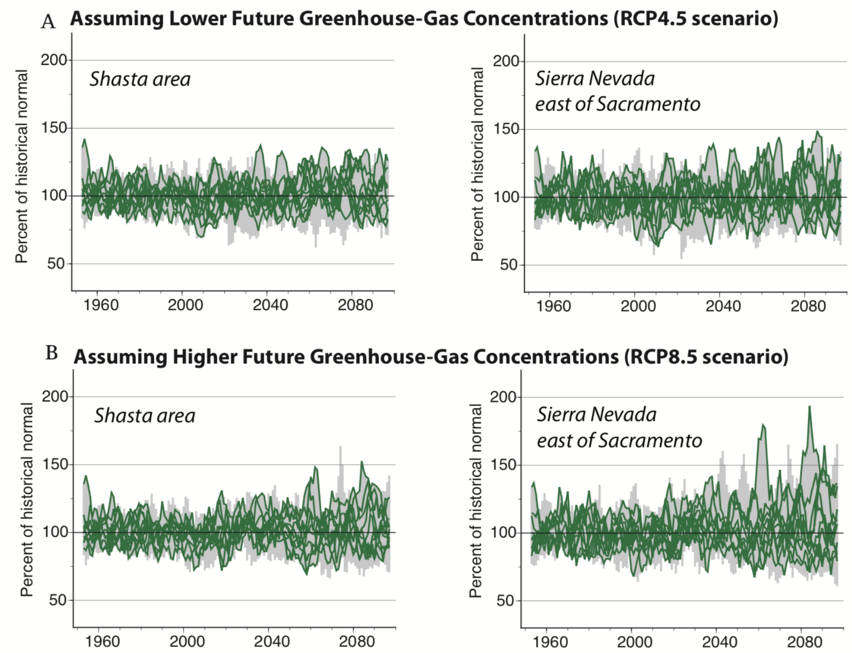
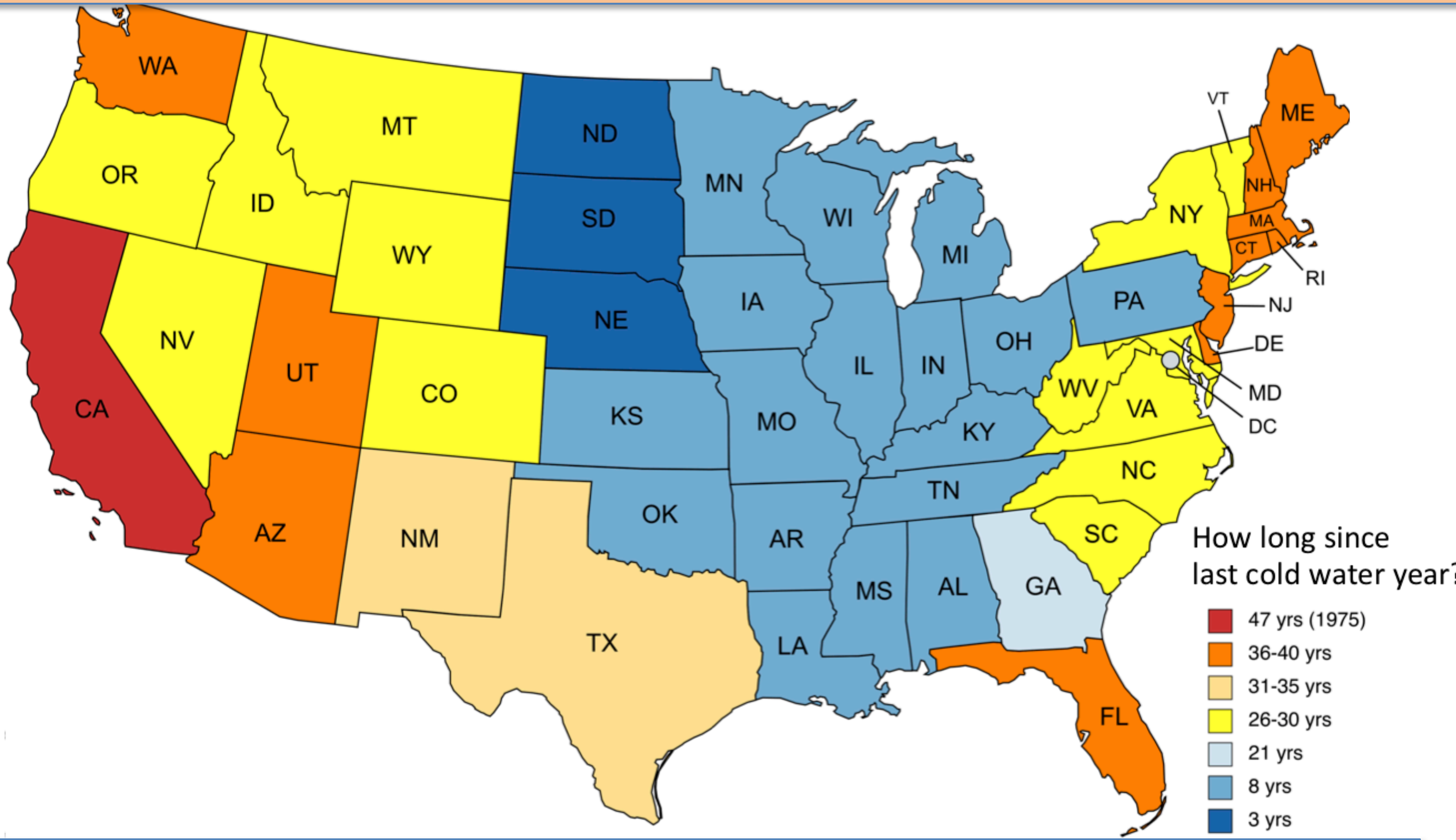


Figure 3 Projected annual changes in precipitation, relative to 1961–1990 averages, in 10 selected global climate models (bright curves, 5-year moving averaged) and in 31 models (grey, unsmoothed), under low **(A)** and high **(B)** future greenhouse-gas emissions. (Source: CDWR Climate Change Technical Advisory Group 2015).

Dettinger et al, SFEWS, 2016

OBSERVED(?!) lack of cold years



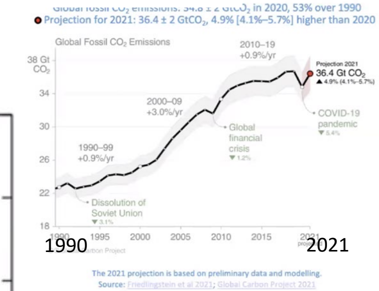
Do you really remember what a cold year is like?

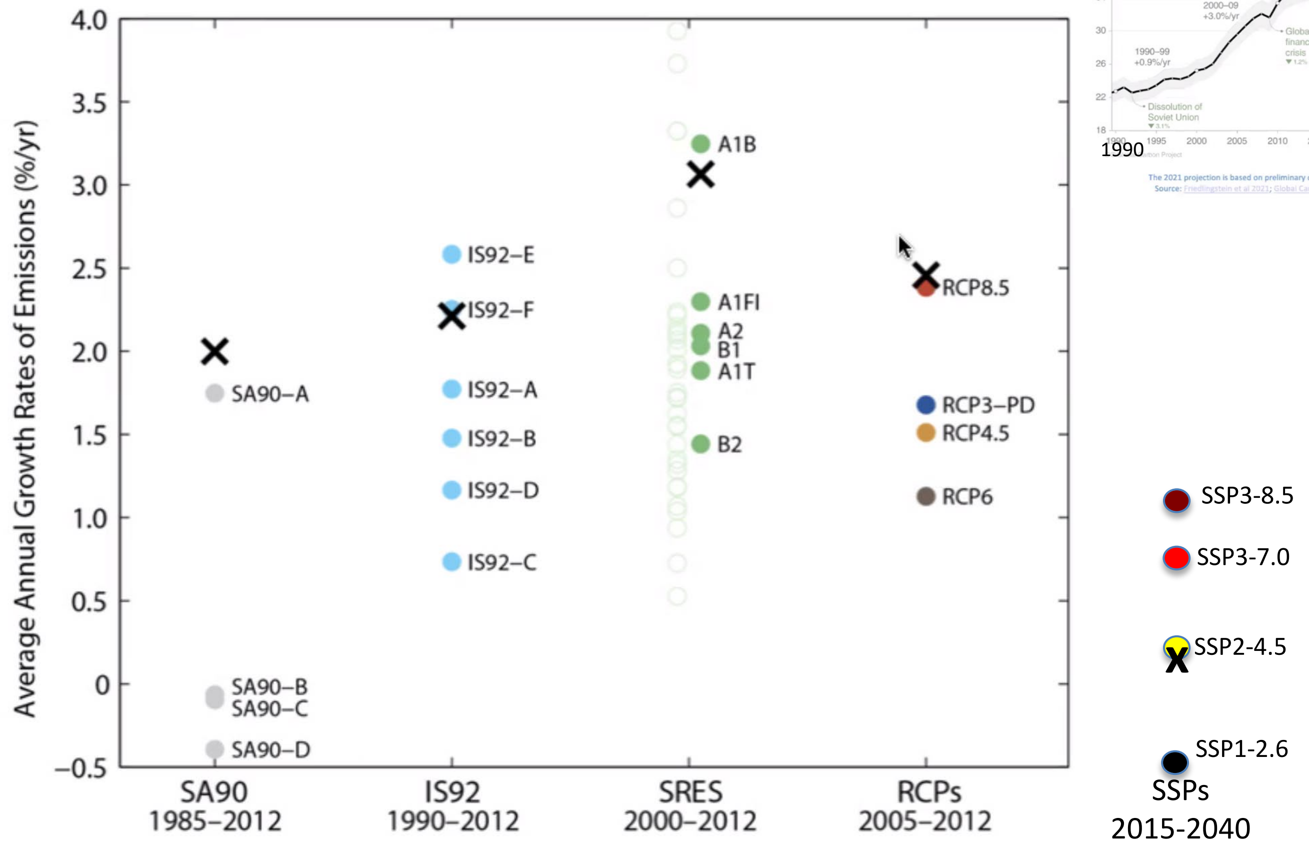
Its been more than 25 yrs since a state in the West (and most of the East Coast) has experienced a water year as cold as one of its 20th Century coolest 25%!

Updated: Thru wy2022

Observed emissions (X) continue to track the top-end of all scenarios (●)

until recently?





Crosses (X) : Historical emissions growth over the period in horizontal axis

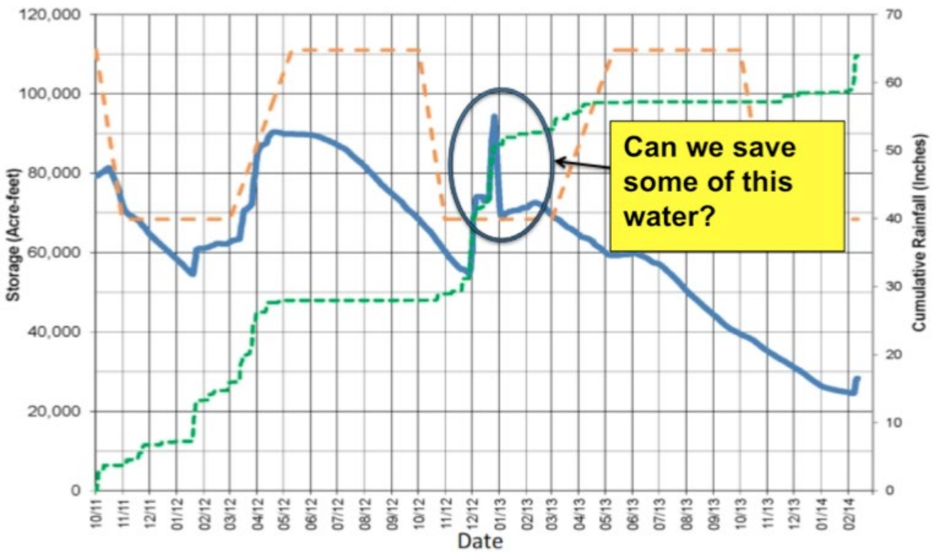
Circles (●) : Scenario emissions growth over the period in horizontal axis

Source: Peters et al. 2012a; Global Carbon Project 2012

Note to NASEM: This slide is modified from one obtained from Prof. E. Eltahir, MIT, who I suspect got the original from someone else. I (Dettinger) added the symbols on the far right (outside the graph) based on the inset graphic time series of emissions since 1990. I would NOT recommend relying on these figures without checking them yourselves.

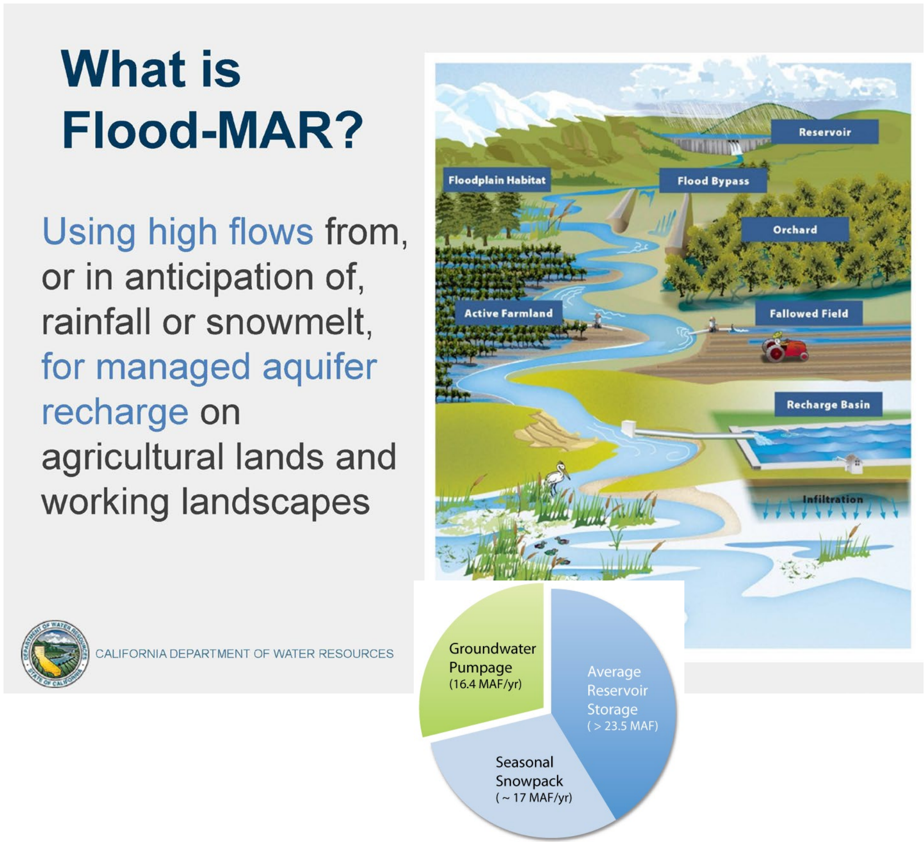
What would California water resources mgmt reliant on extremes look like?

FIRO:
Forecast-informed Reservoir Operations



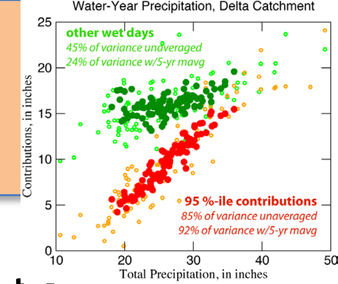
Lake Mendocino FIRO FVA 2020

Flood-MAR:
Rerouting flood waters to recharge overdrafted aquifers for later use

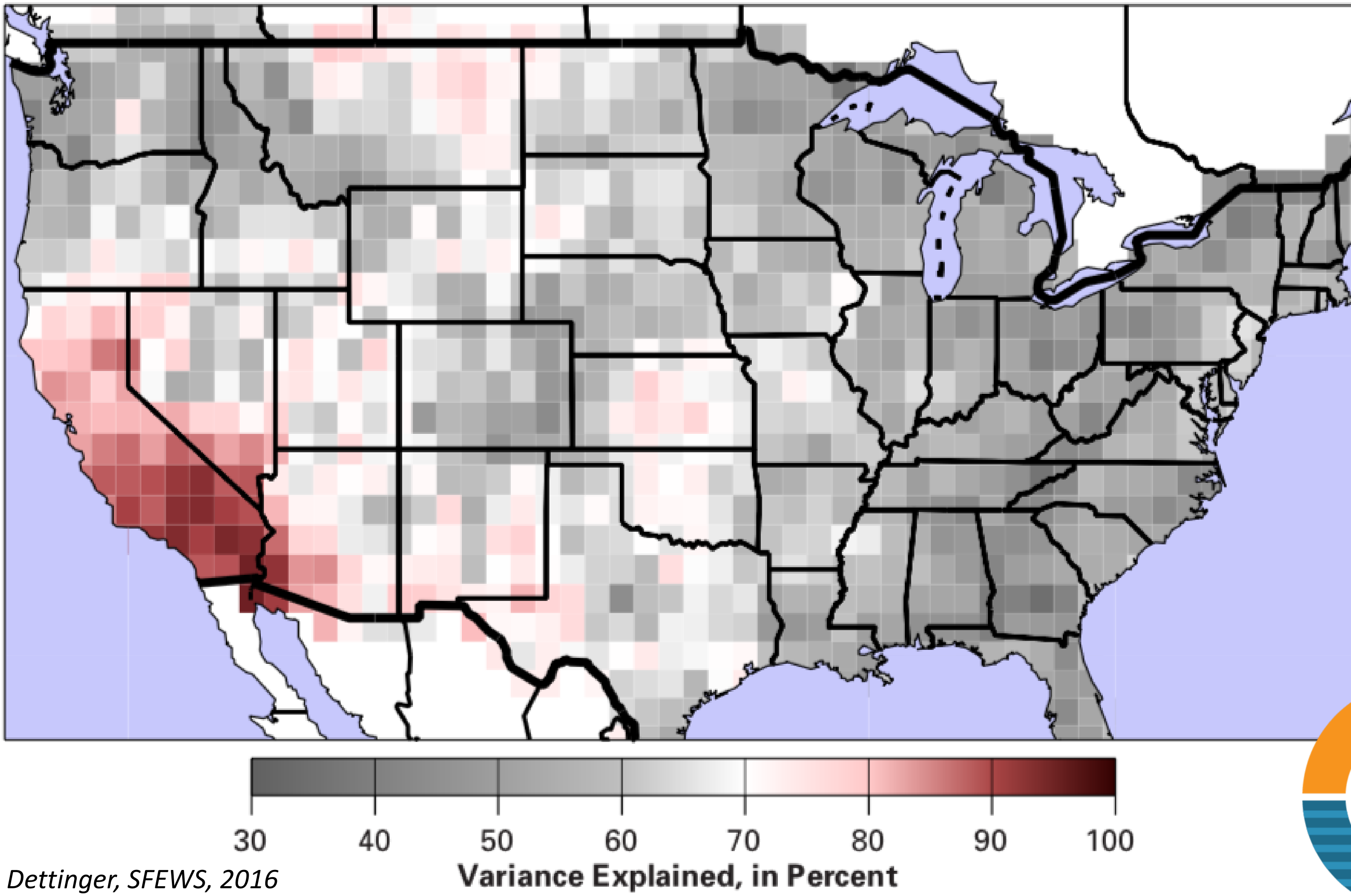


https://water.ca.gov/programs/all-programs/flood-mar

2. …and this is almost UNIQUELY a California "thing"



Percentage of Water-Year Precip Variance explained by Precip from wettest 7 days/yr



Dettinger, SFEWS, 2016

Science Strategies in the Face of Climate Change (2008)

Table 1. Climate Change Challenges and Strategic Responses

Challenges	Strategic Responses
1. Human-induced climate changes have already begun, and are expected to continue	• Require long-term monitoring commitments from restoration and resource-management activities • Increase climate-science literacy and education • Prioritize ecosystem adaptability in restoration efforts • Evaluate opportunities for operational responses
2. Changes will be multi-variate	• Support multi-disciplinary science • Encourage multi-variate climate monitoring and modeling
3. Change will be geographically pervasive	• Ensure consistency of observational and analytical methods across the region • Focus on geographic connections • Expect California to be highly sensitive
4. Change will be rapid	• Identify maximum rates of adaptability • Undertake manipulative experiments • Consider artificial refugia and seed banking
5. Projections are, and will remain, uncertain	• Address more certain projections directly and less certain changes by increasing flexibility • Pursue risk-based decision-making • Support competing hypotheses • Explore contradictions • Develop and maintain multiple models of important subsystems • Reduce reliance on statistical models • Adopt standard terminologies for uncertainty
6. Effects will interact	• Integrate models • Coordinate across scientific disciplines • Focus on extreme events • Consider energy and greenhouse consequences
7. Surprises are likely	• Emphasize prediction nonetheless • Balance predictive vs. tracking strategies • Increase management flexibility • Expand diversity of response options

Dettinger & Culberson, SFEWS, 2008