CALIFORNIA DEPARTMENT OF WATER RESOURCES

Potential Flood Risk Associated with Climate Change in Central Valley: Comparison of ARkStorm 2.0, Central Valley Flood Protection Plan, and Weather Generator

April 17th, 2023

CWEMF 2023

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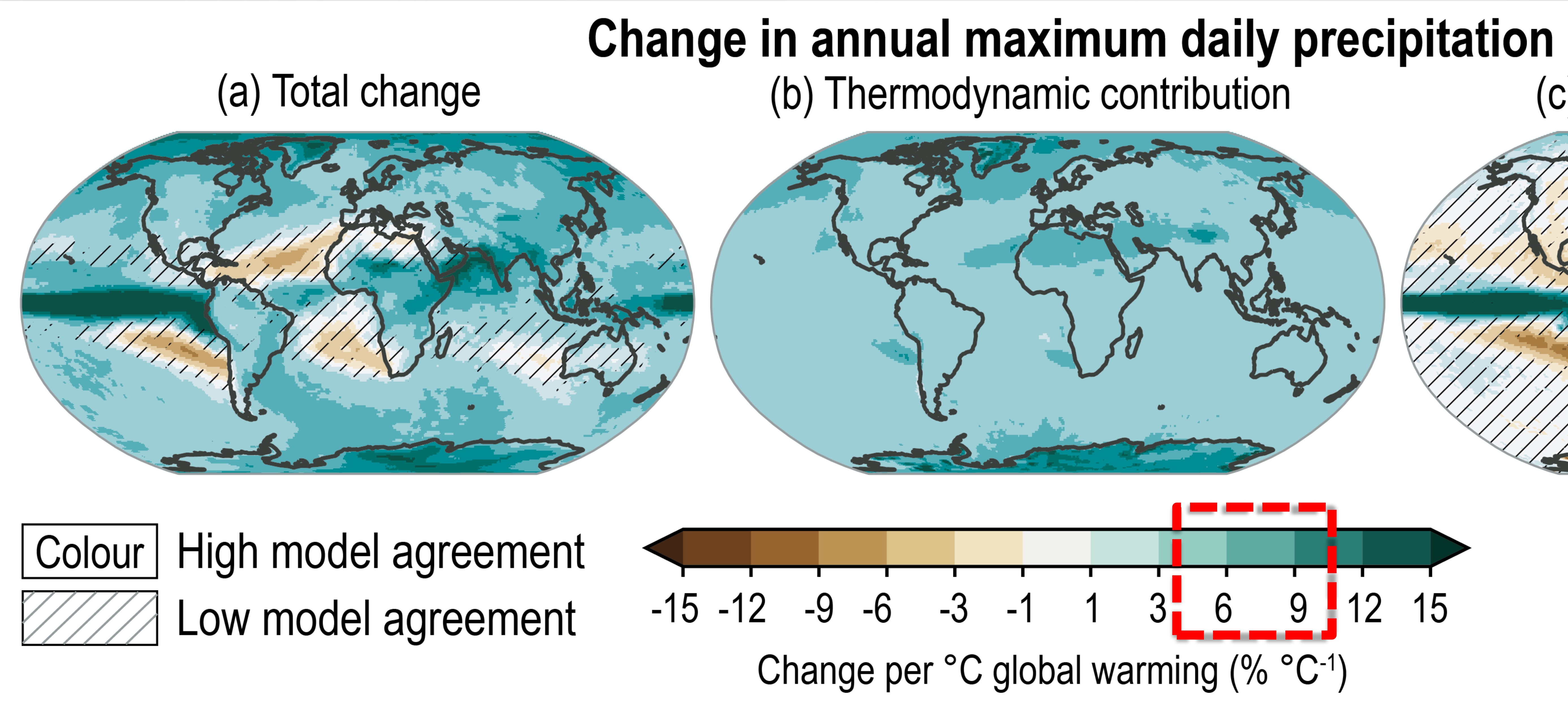
Today's Presentation

- Climate Change Science and Understanding
- Climate Change Analytical Approach
  - ARkStorm Scenario
  - Central Valley Flood Protection Plan (CVFPP) 2022
  - Weather Generator Perturbations
- Comparisons
  - Temperature
  - Precipitation
  - Unregulated Flow

Intergovernmental Panel on Climate Change (IPCC) and Coupled Model Intercomparison Project (CMIP)

IPCC Assessment Report (AR)	CMIP & Number of General Circulation Model (GCM)	Name and Number of Greenhouse Gas (GHG) Scenarios
1st (1990)		
2nd (1995)		
3rd (2001)	CMIP1/2 ~18 models (1997)	Special Report on Emissions Scenarios (SRES) – 6 Scenarios
4th (2007)	CMIP3 24 models (2006)	SRES – 6 Scenarios
5th (2014)	CMIP5 40 models (2014)	Representative Concentration Pathways (RCP) – 7 Scenarios, but only 4 are used in AR5
6th (2021/22)	CMIP6 50+ models (2020)	Shared Socioeconomic Pathways (SSP) – 5 Scenarios

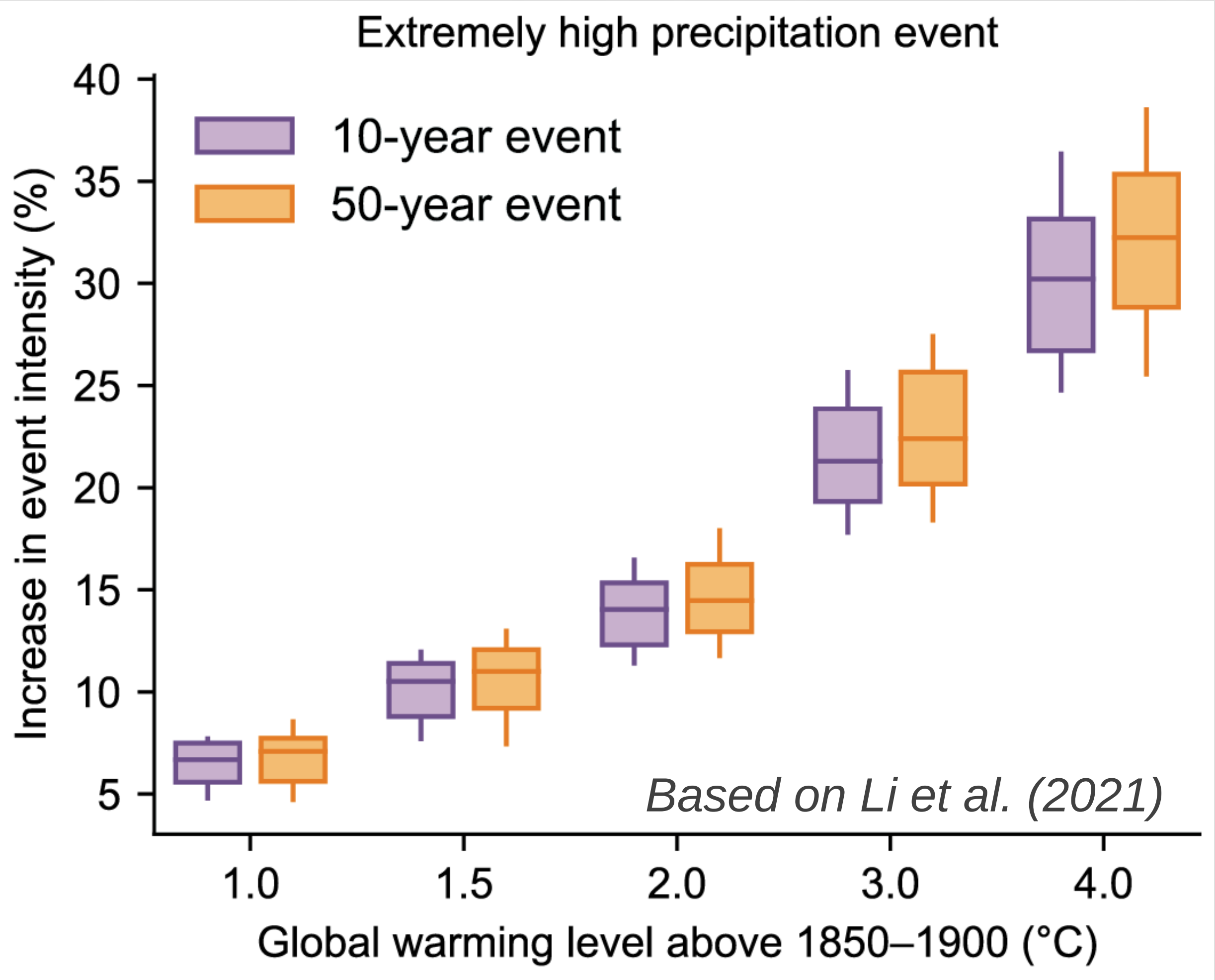
Thermodynamic and Dynamic Contribution to Annual Maximum Daily Precipitation



- Inter-Annual
- Precipitation

- Temperature Change
- Clausius-Clapeyron

Projected changes in the intensity of extreme



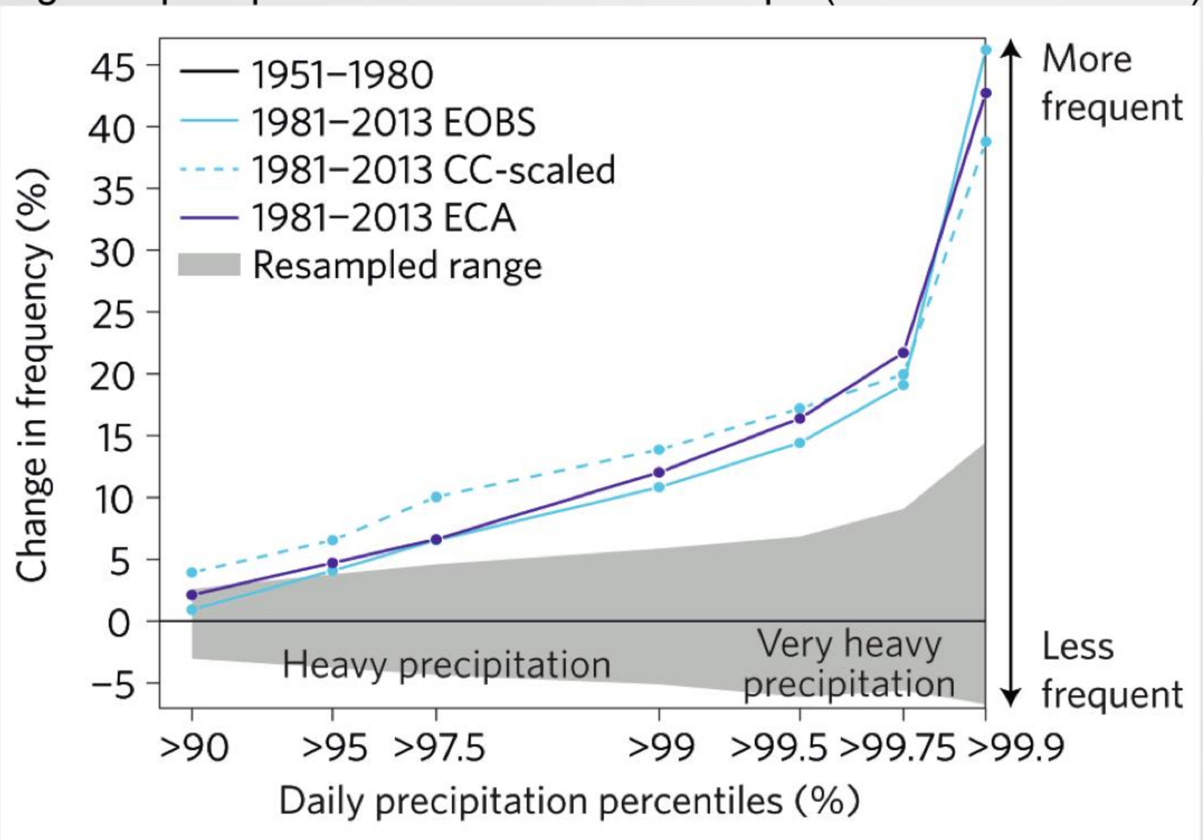
PERSPECTIVE
PUBLISHED ONLINE: 26 OCTOBER 2016 | DOI: 10.1038/NCLIMATE3110
nature climate change

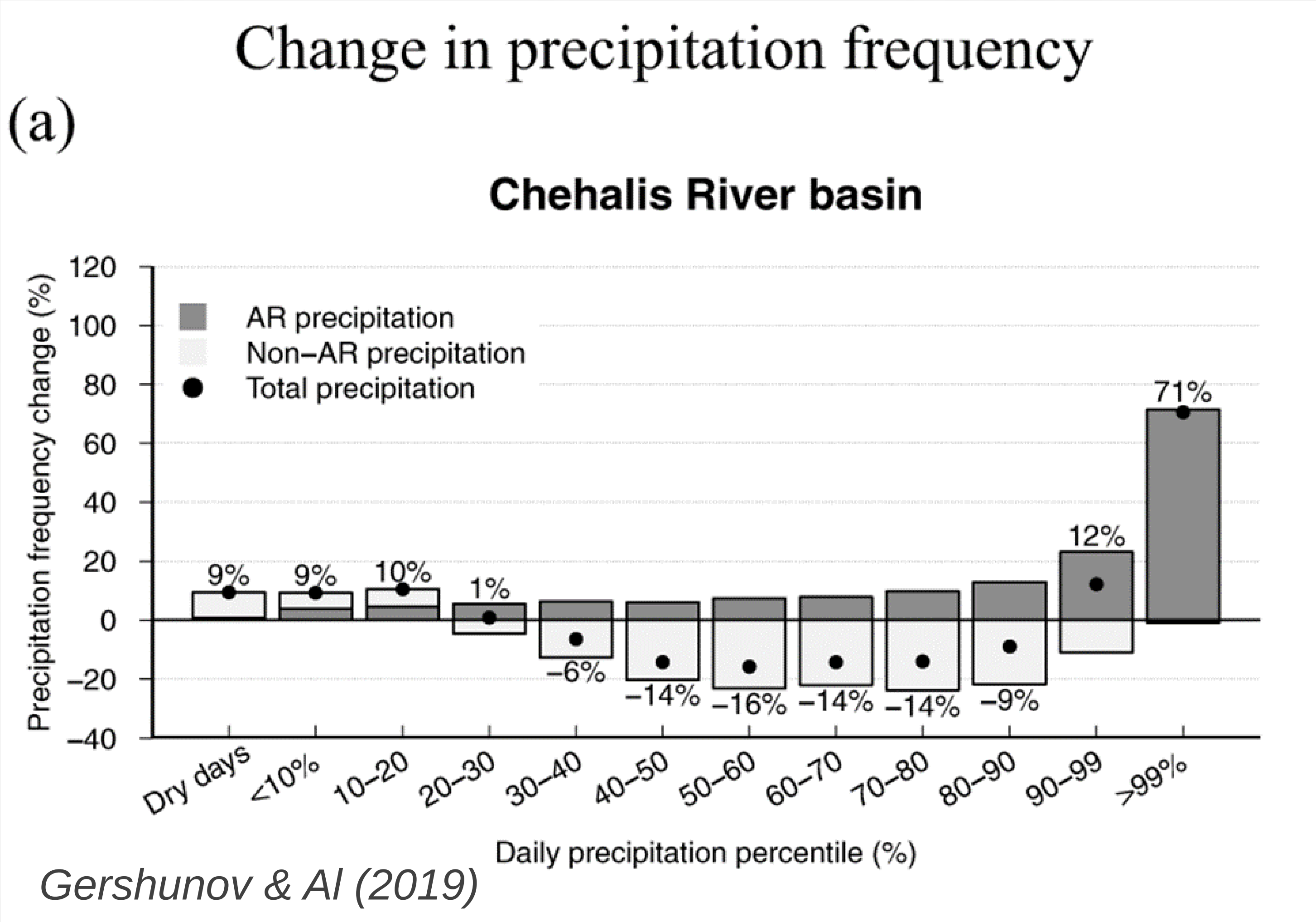
Observed heavy precipitation increase confirms theory and early models

E. M. Fischer* and R. Knutti

Theory – Clausius-Clapeyron (1834)
Models – Extreme and average precipitation change differ under warming (1980s)
Observations – trends in extreme precipitation are detectable (2000s)

Changes in precipitation extremes over Europe (obs and CC scaled)





Earth's Future

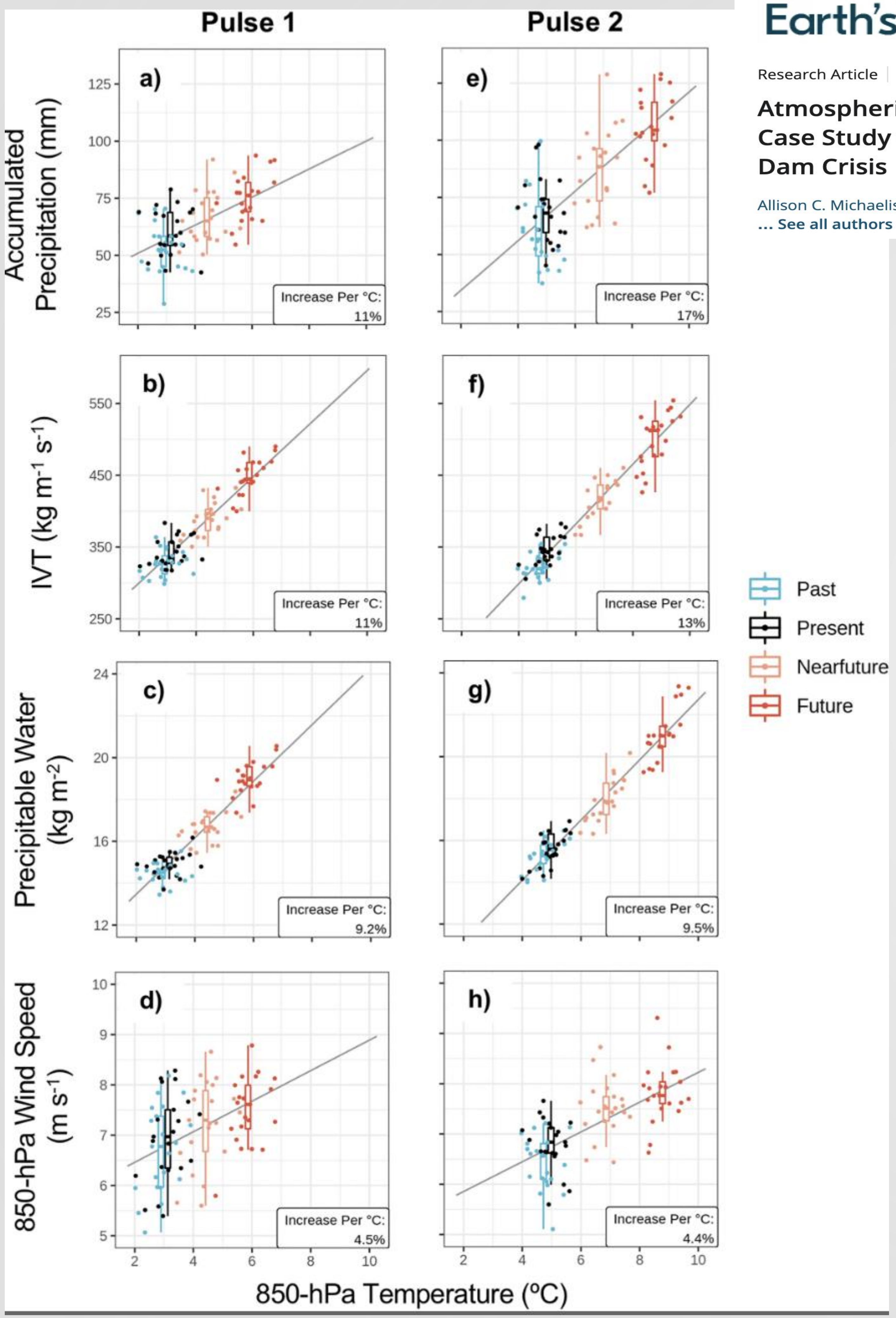
Research Article | Open Access

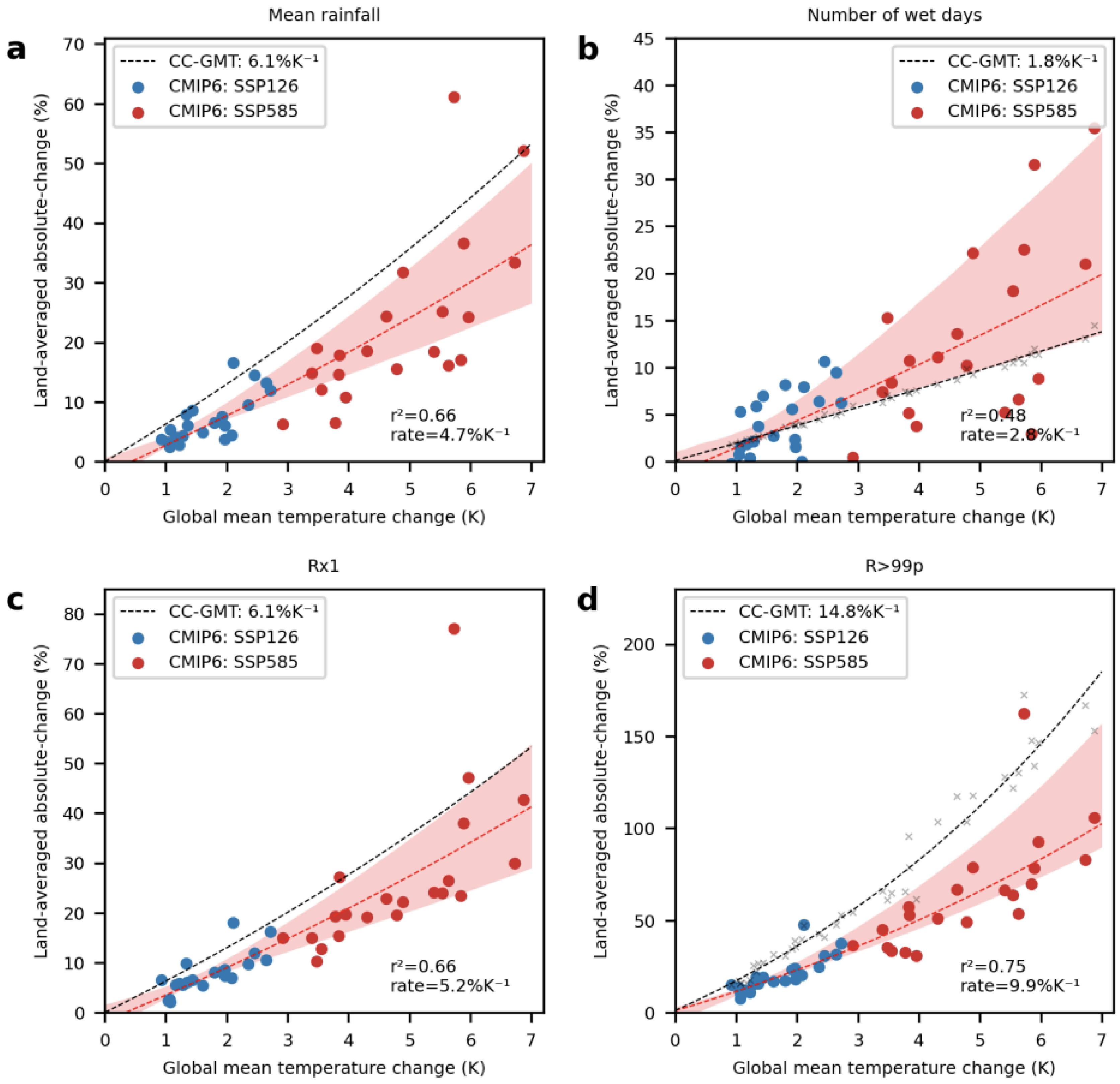
Atmospheric River Precipitation Enhanced by Climate Change: A Case Study of the Storm That Contributed to California's Oroville Dam Crisis

Allison C. Michaelis, Alexander Gershunov, Alexander Weyant, Meredith A. Fish, Tamara Shulgina
... See all authors

Changes in mean and extreme precipitation scale universally with global mean temperature across and within climate models

Maximilian Kotz[a b], Stefan Lange[a], Leonie Wenz[a c], Anders Levermann[a b d]



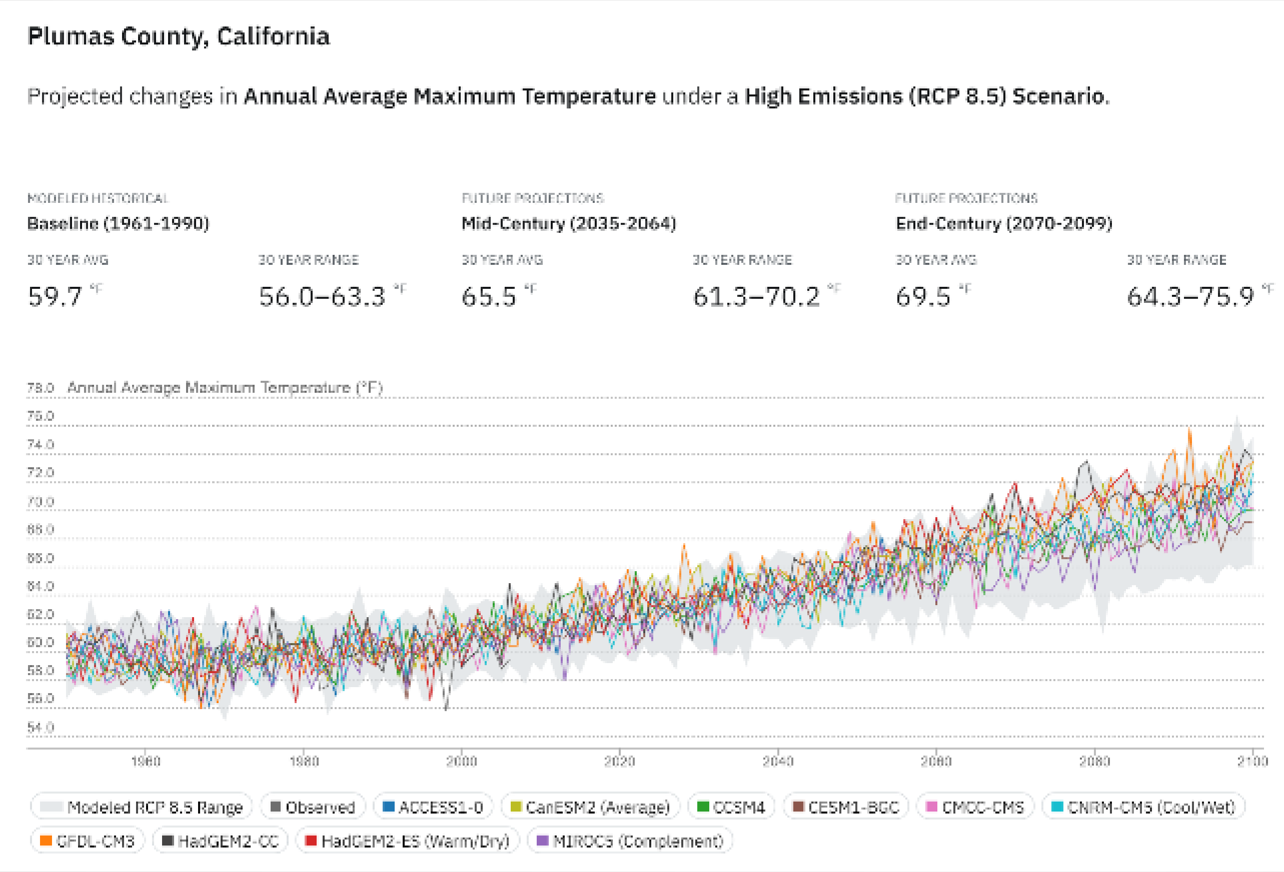


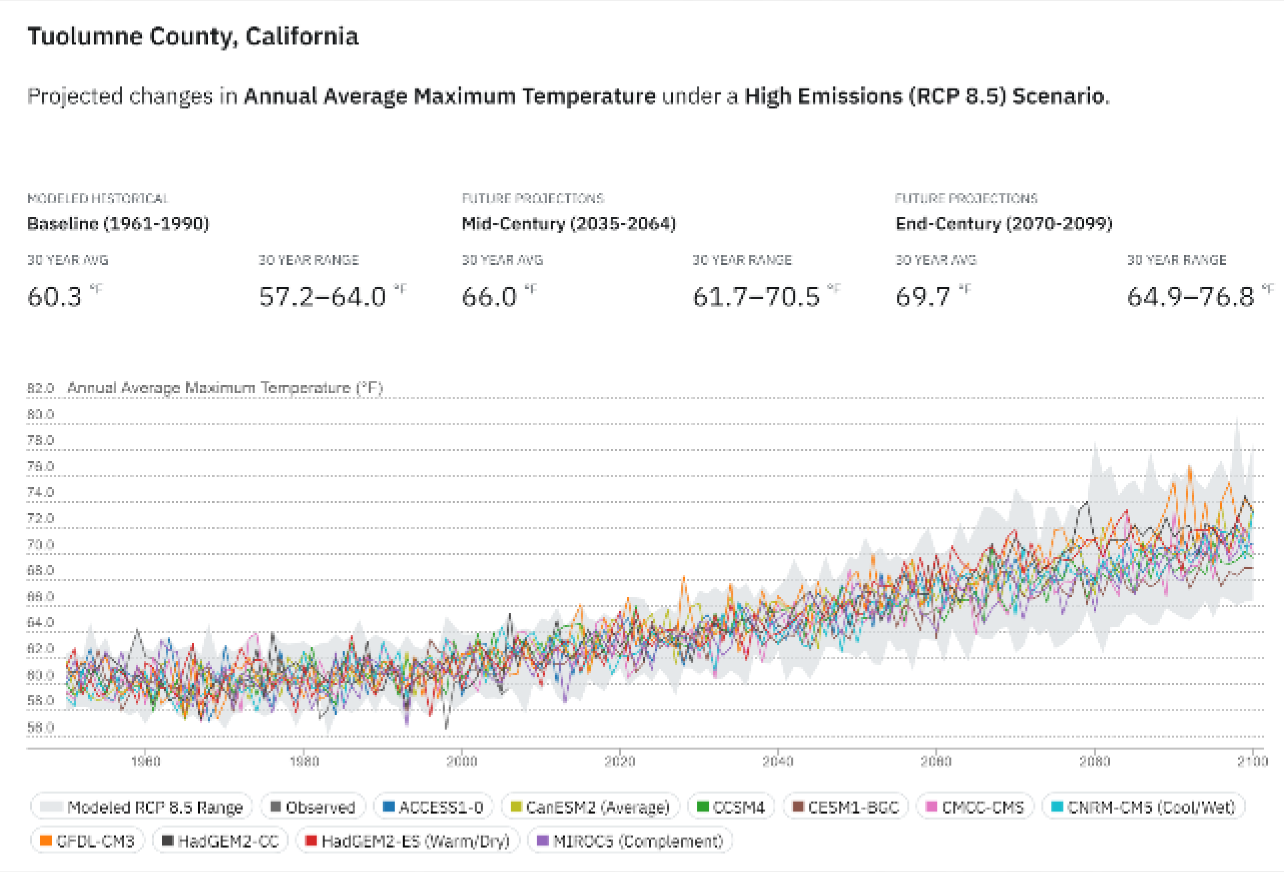
What does CalAdapt tell us?

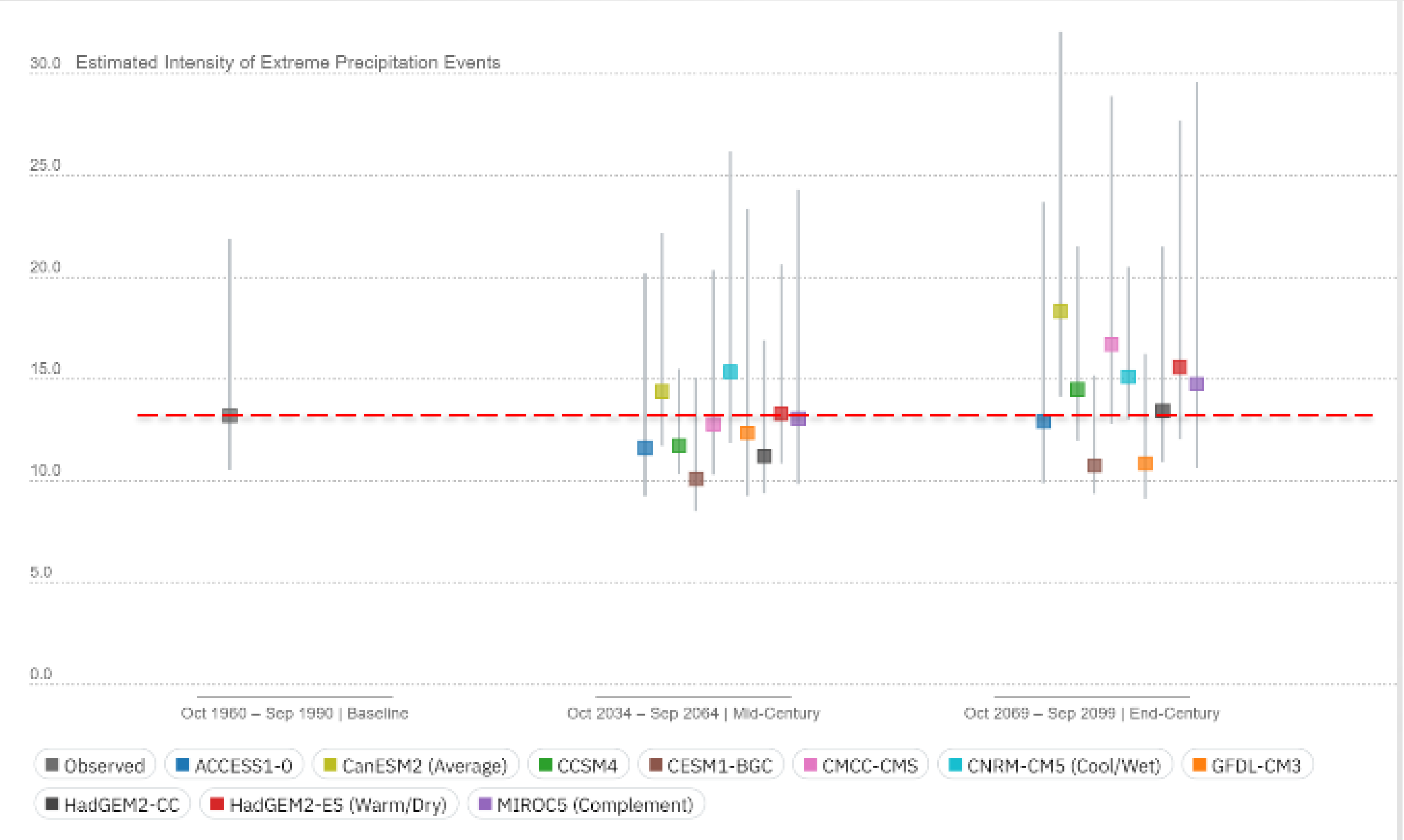
Projections Using the 10 Climate Change Technical Advisory Group with RCP8.5

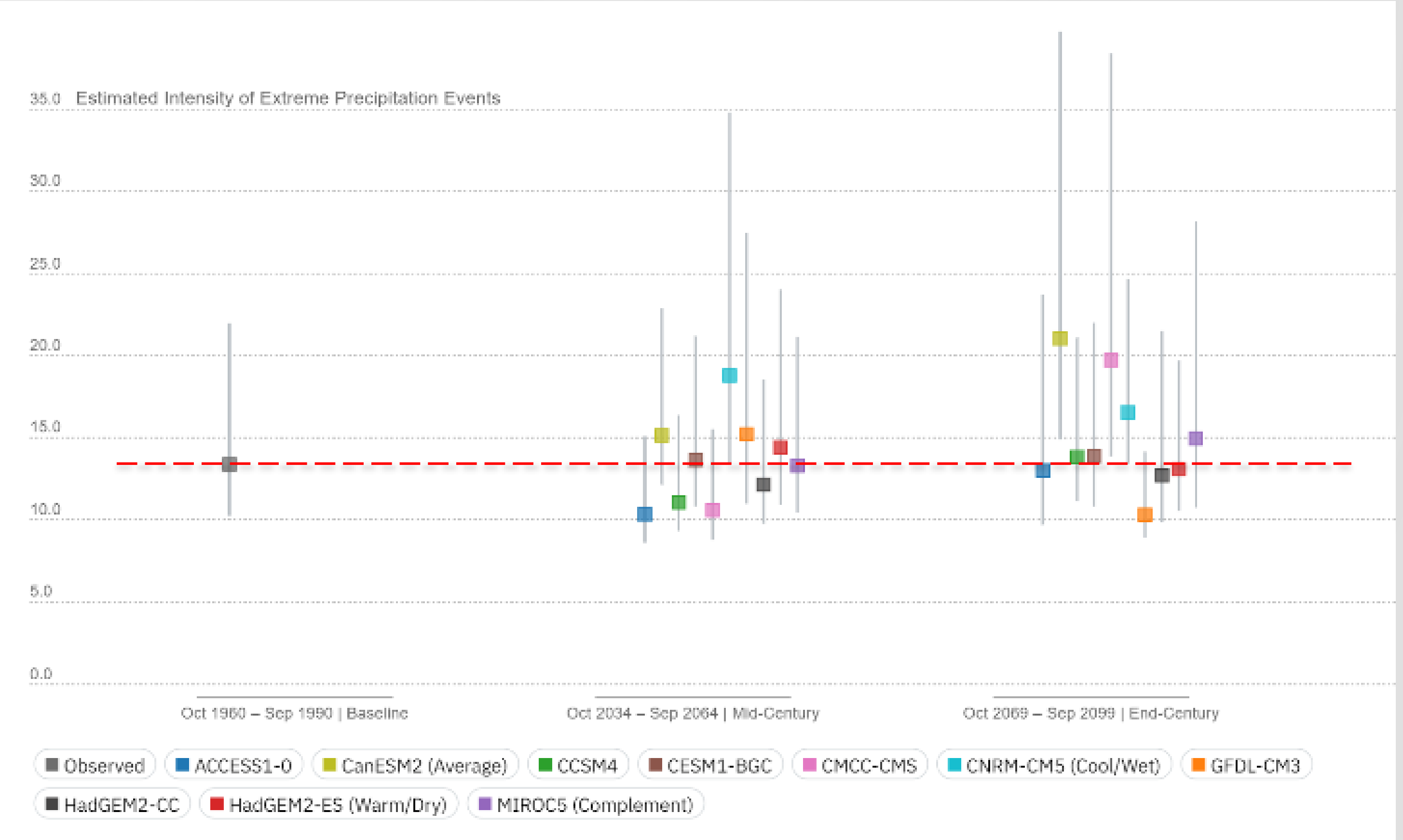
- Average Annual Temperature Change

- 100-yr 3-day Rainfall Intensity









https://cal-adapt.org/

Climate Change Analytical Approach

Using Climate Projections at DWR

"Top Down" or **Downscaling** Approach

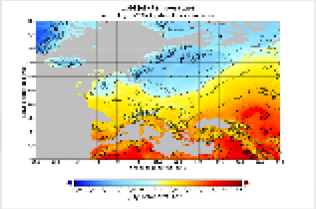
Select a Couple of General Circulation Model (GCM) Projections

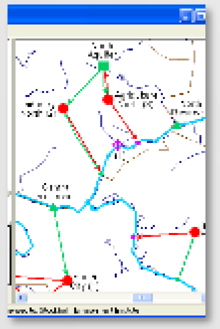
Downscaling, Hydrologic Modeling

Operations and Planning Models

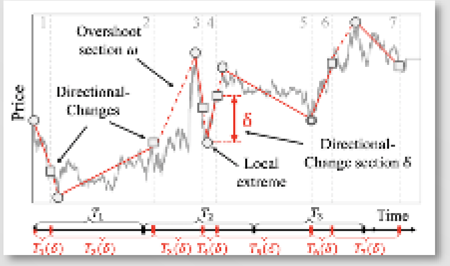
Conditional System Performance Projections

Source: [NOAA GFDL]





Source: [SEI WEAP]



Original method of developing climate change plans

There are 100's of Global Climate projections

→ Pick a scenario or set of scenarios to localize and use as the "future"

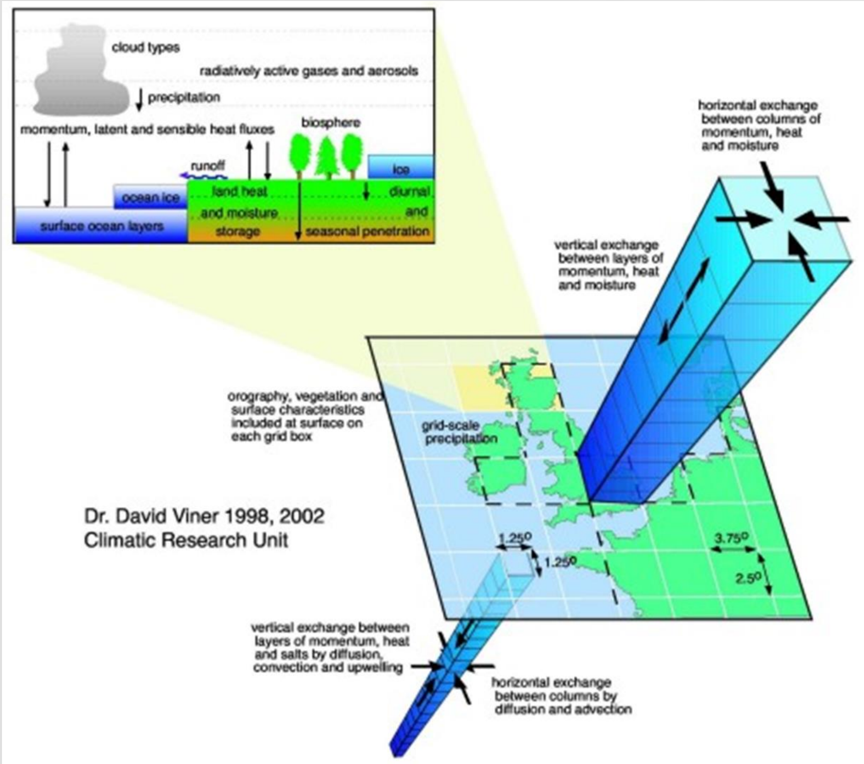
→ Predict future performance of your water system

→ Determine vulnerabilities and adapt as indicated

- Did we cover the full range of uncertainty to be prepared?
- Would the results be different if a different set of projections or method were used?
- How likely is this future, what is the risk?

ARkStorm Approach

General Circulation Model (GCM)
(1GCM + 1RCPs + 40Members=400-model Year)

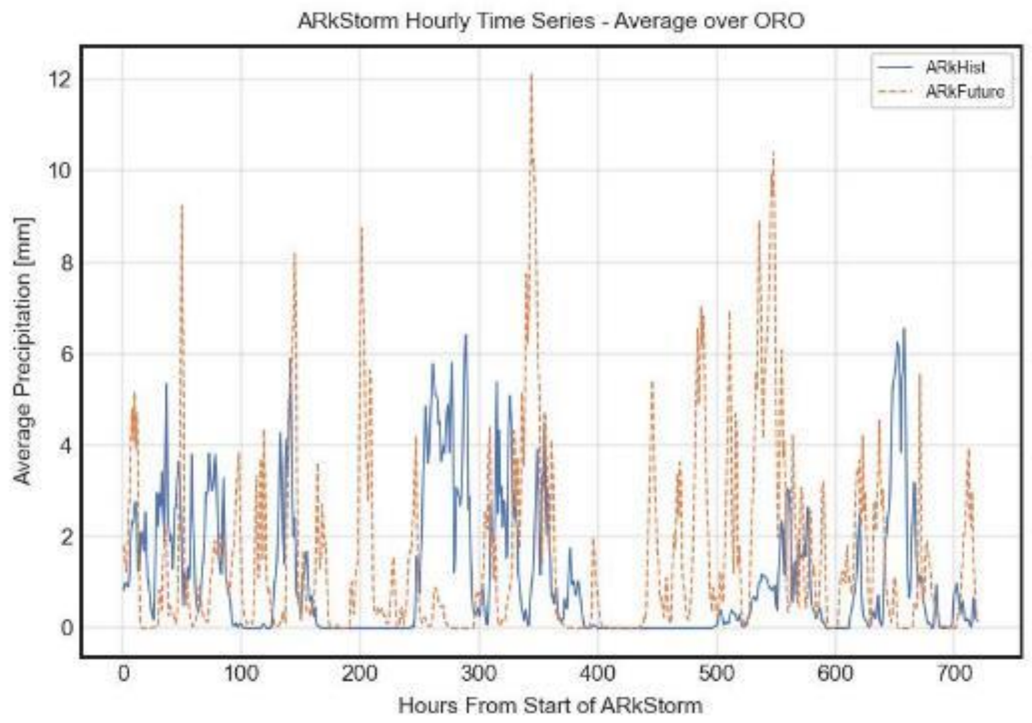


Dynamically downscaled using WRF at 3KM (1.9 miles)

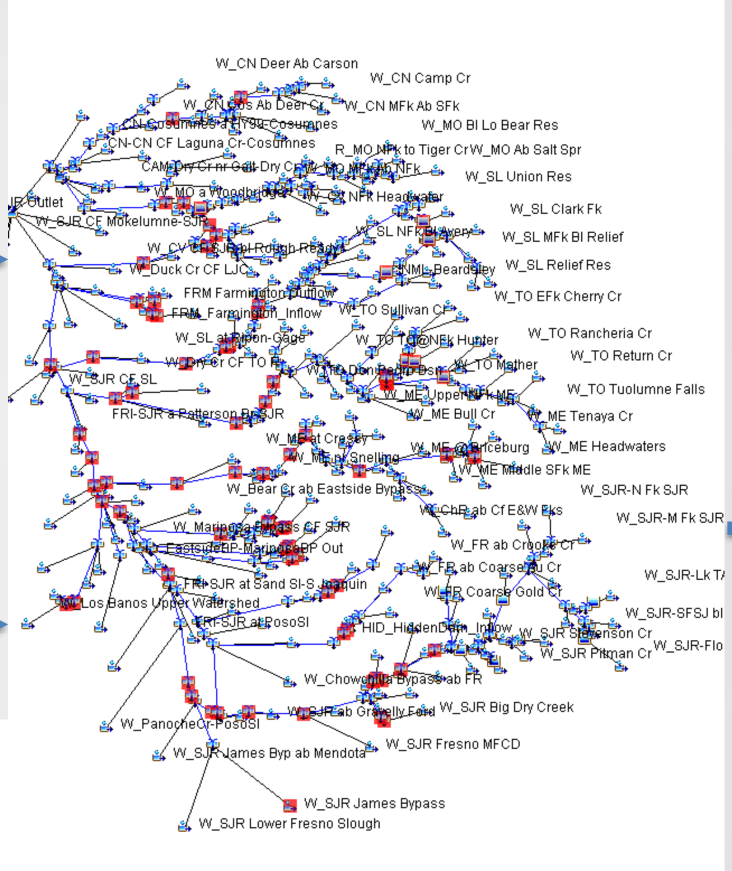
Rank top 3, 30-day storms sequence –
Rainfall-Runoff Model Inputs

Precipitation

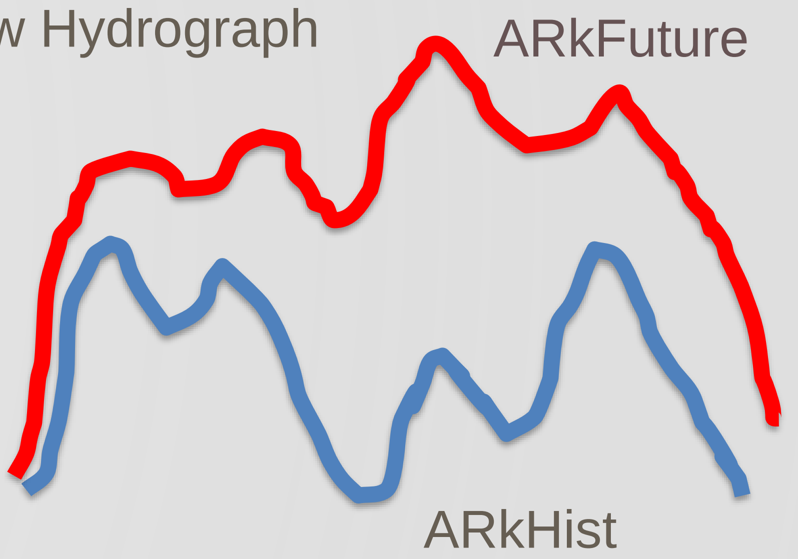
Temperature



Rainfall-Runoff Model
(HEC-HMS)

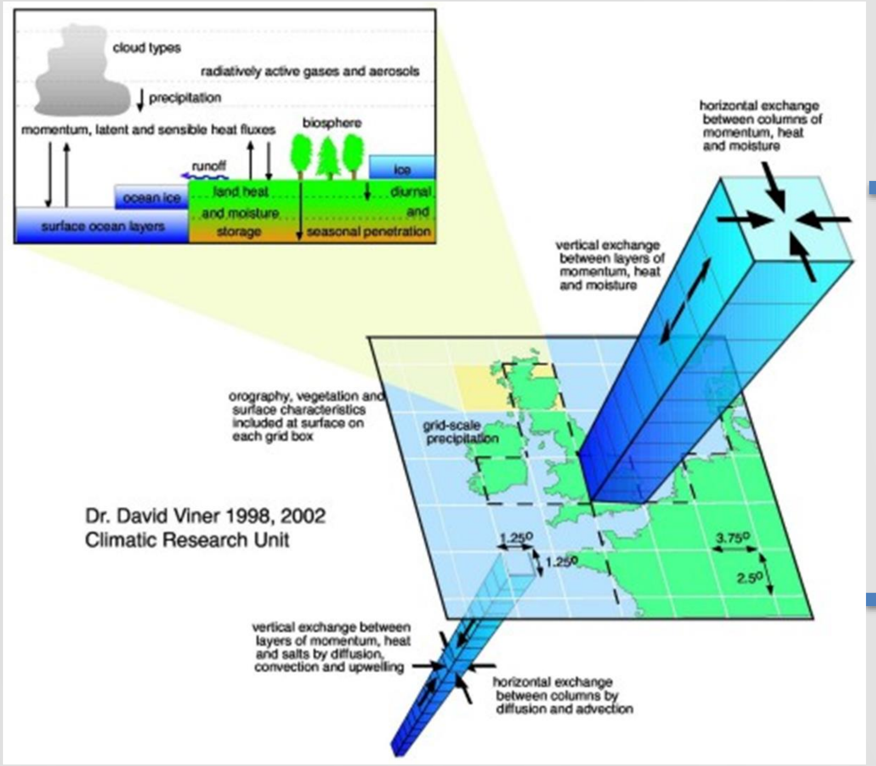


HEC-HMS Outputs
30Days simulations



CVFPP Climate Change Approach

General Circulation Model (GCM) (32GCMs + 2RCPs)



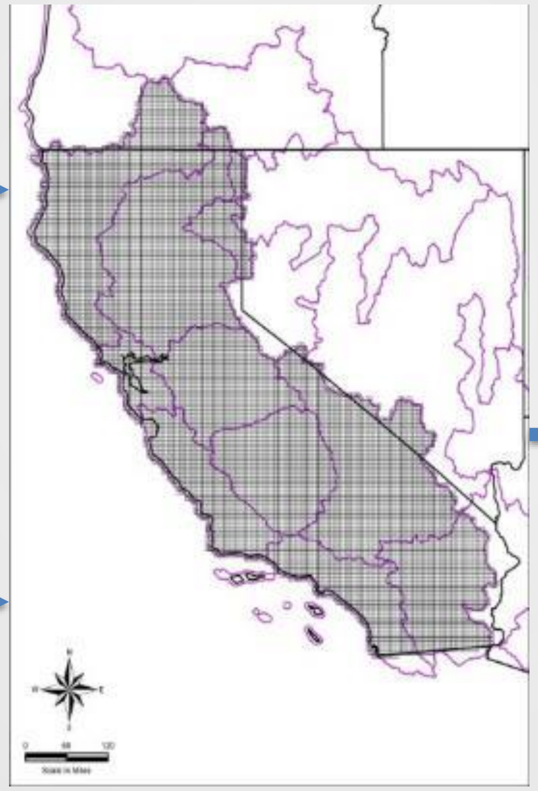
Downscaled at 1/16th degree
6 kilometers (3.75 miles)

GCM Outputs – Rainfall-Runoff Model Inputs

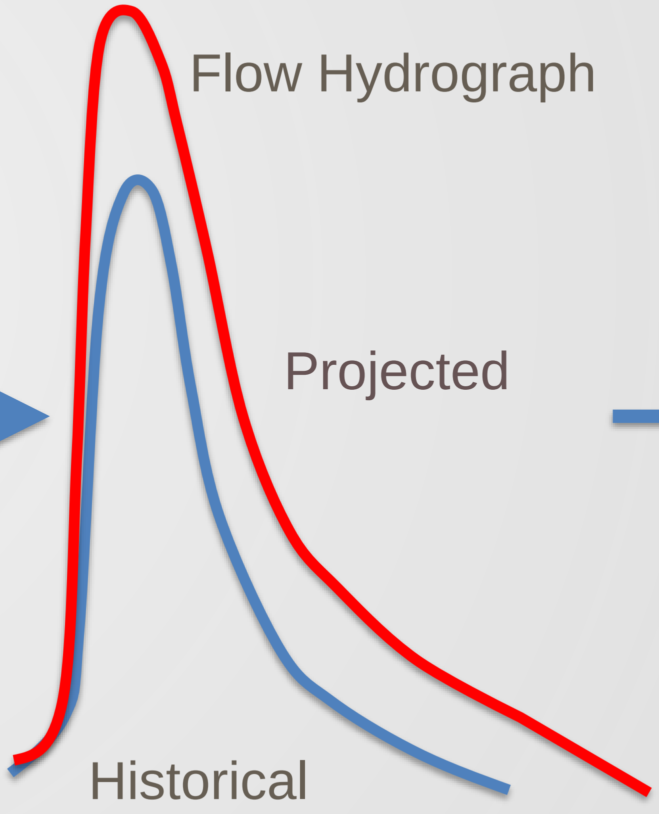
Temperature

Precipitation

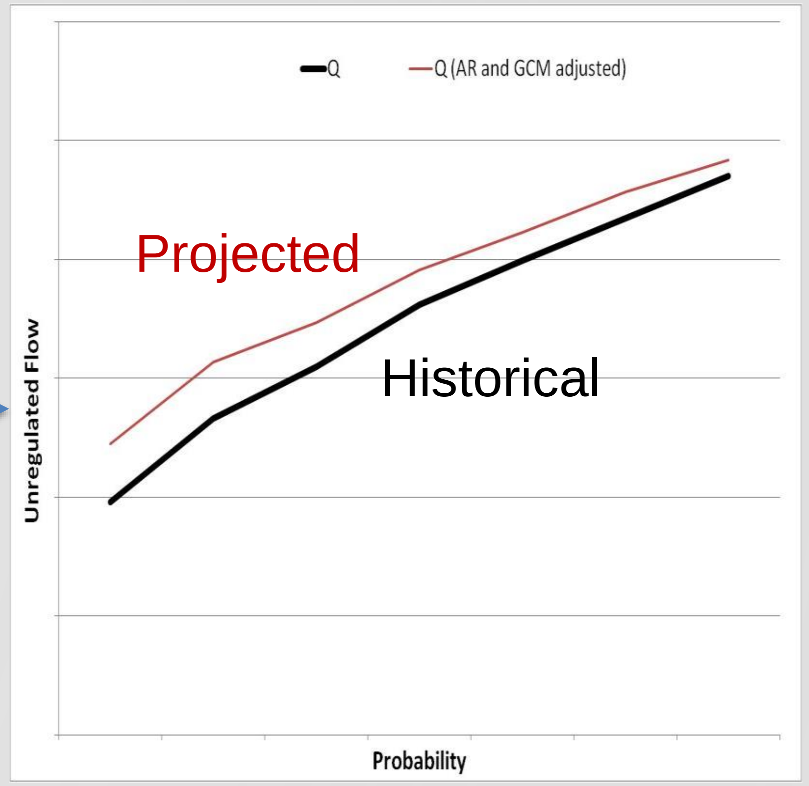
Rainfall-Runoff Model (VIC Model)



VIC Outputs
97 years simulations

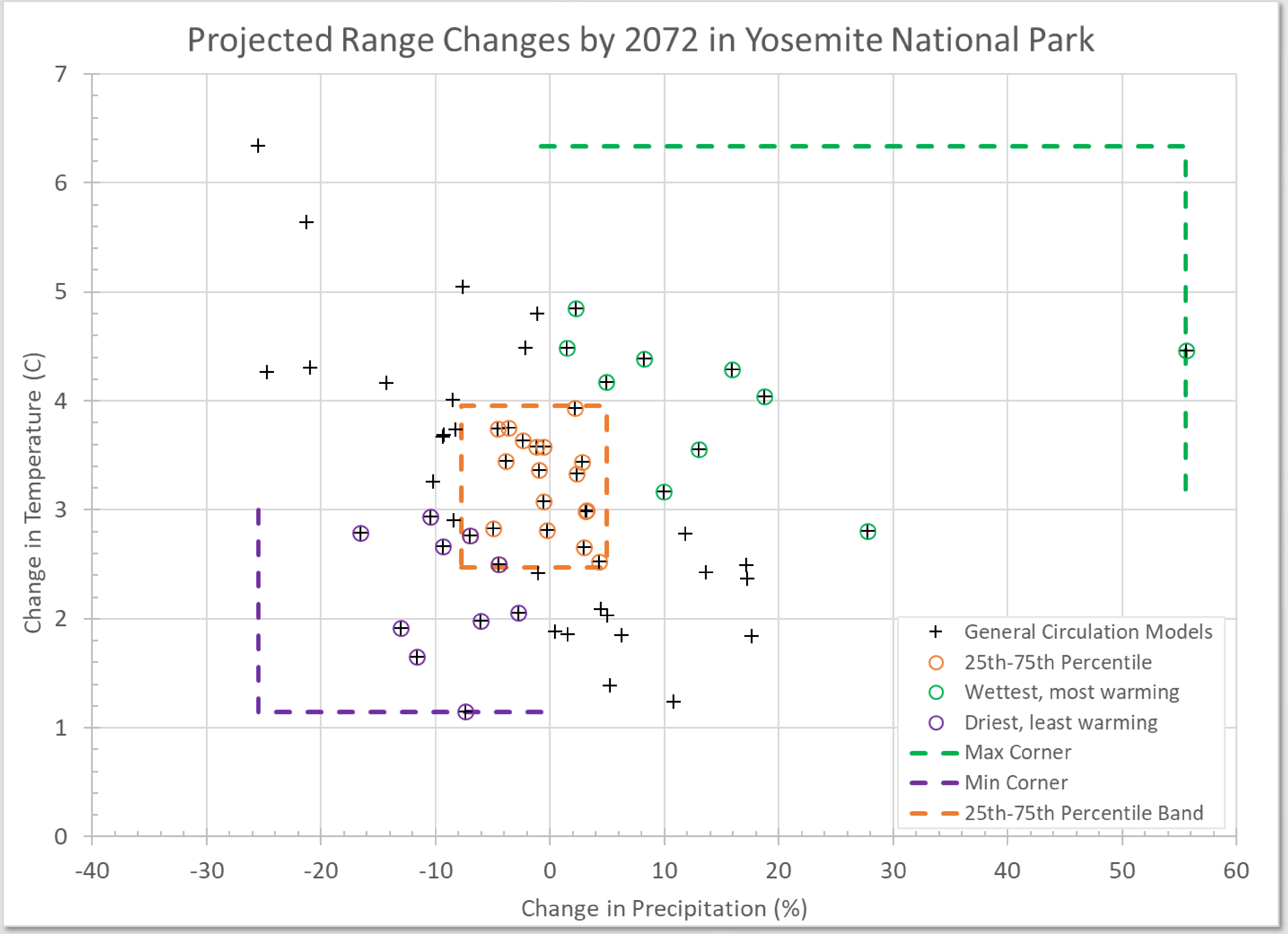


Adjusted Unregulated Flow Frequency Curves for Climate Change



$$\text{Climate Change Factor}_{\text{(AEP)(n-day volume)}} = \frac{\textit{Projected Peak volume}_{(AEP)(n-day\ volume)}}{\textit{Historical Peak Volume}_{(AEP)(n-day\ volume)}}$$

2022 Central Valley Flood Protection Plan Update (CVFPP)



- Select a sub-set of GCM
- Collect climate change stressors:
  - Temperature
  - Precipitation
- Statistical distribution applied to historical data (1905-2011)

Using Climate Projections at DWR

"Bottom Up" or **Decision Scaling** Approach

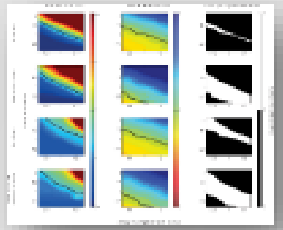
Adaptive Planning

Climate Model Ensemble

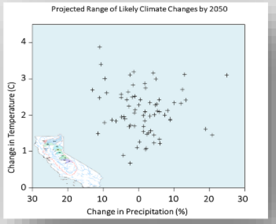
System Surface Response /Vulnerability Assessment

Operations and Planning Models

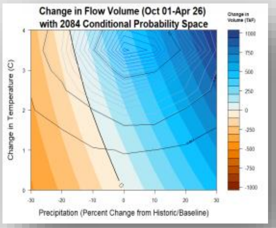
Climate/ Weather Generator or Paleoclimate Data

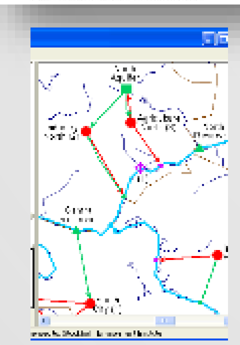


Source: Poff et al. (2016)



Source: DWR VA





Source: SEI WEAP

Systematic Climate Perturbations

Other images source: Wikimedia Commons

A way to prepare when you aren't sure what's coming (Stress Test)

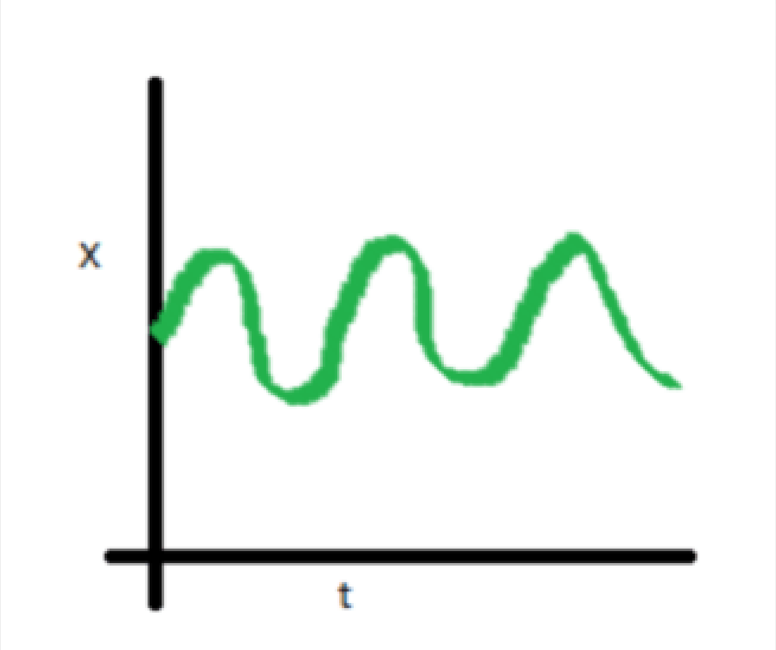
→ Determine the sensitivity of a water system to a range of stress (weather or climate possibilities). **Where is our system vulnerable?**

→ Determine what threshold of performance is unacceptable or 'breaks' the system. **Find tipping points.**

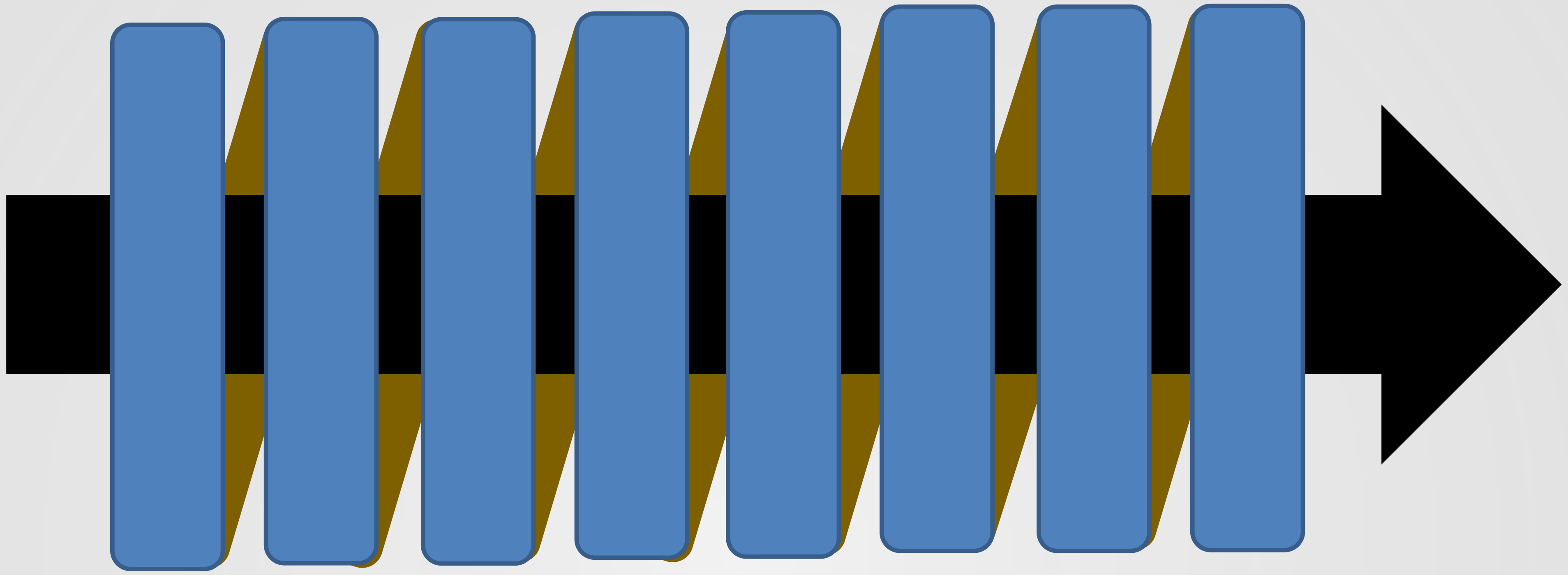
→ Determine how likely that is to happen. **Incorporate original climate projections to assess the risk of these "unacceptable outcomes."**

→ **ADAPT!** Take decision(s) toward what is "most" likely and/or "most" acceptable based on this risk assessment.

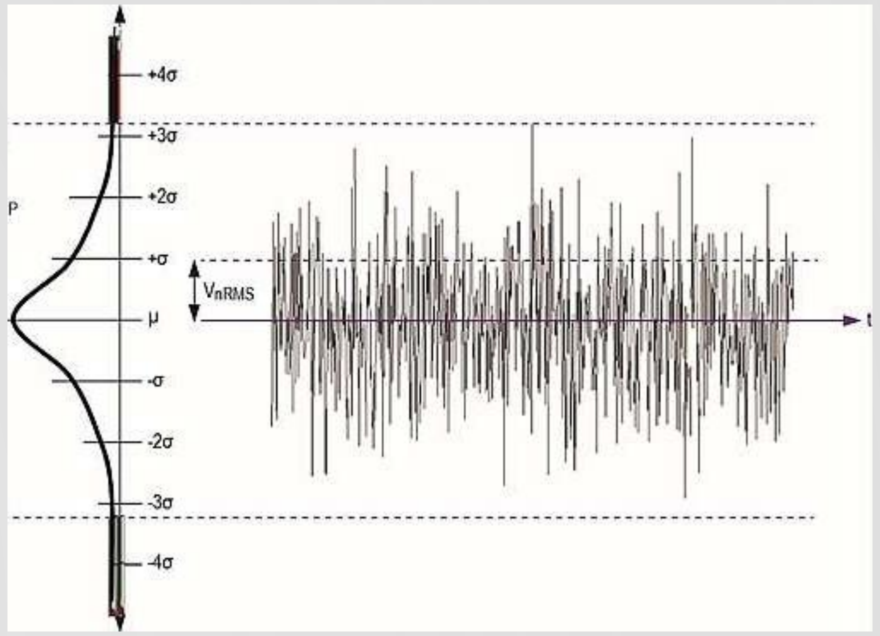
Weather Regime Based Stochastic Weather Generation



Observed or historical time series of weather



- Annual Module
- Seasonal Module
- Daily Module



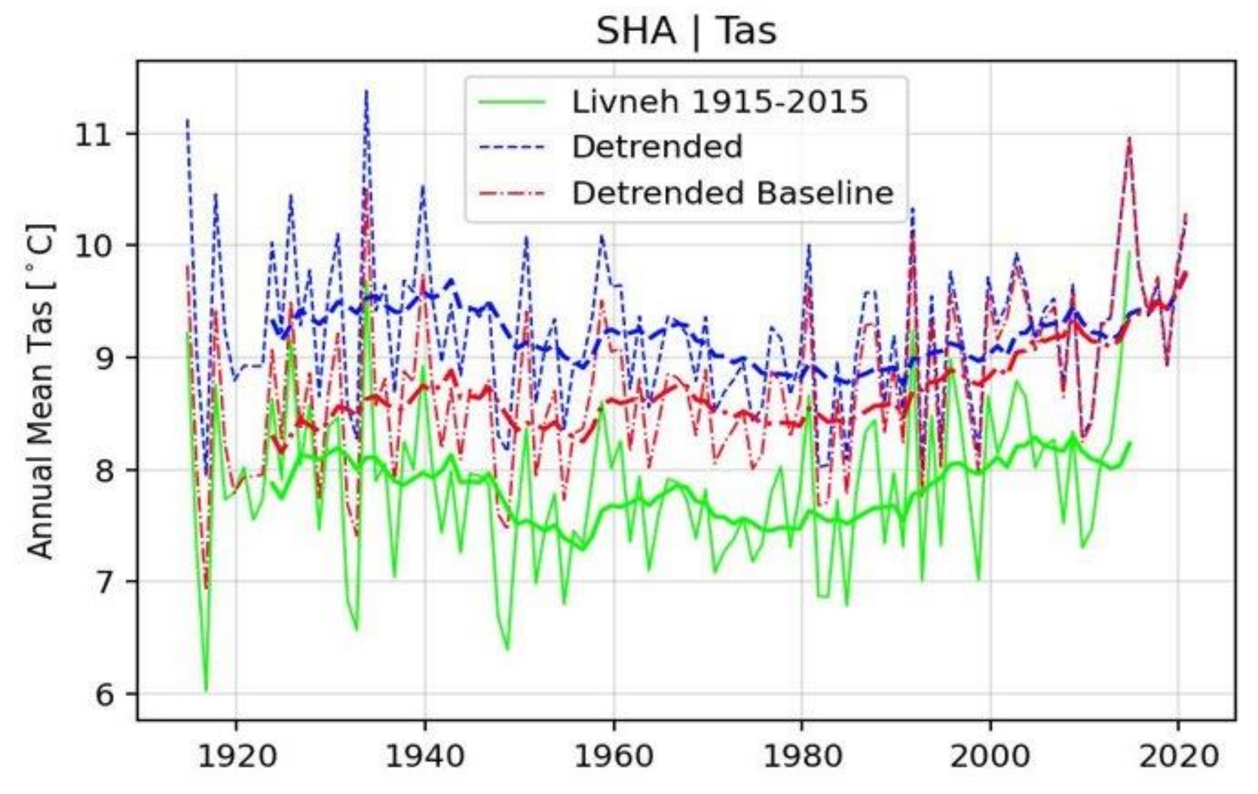
Many simulated time series of weather data

Mid-latitude atmospheric intra-seasonal variability is characterized by large-scale flow patterns (“weather regimes”)

- organize mid-latitude storms
- appear repeatedly at fixed geographical locations
- persist beyond the lifetime of individual synoptic-scale storms (days-weeks)
- exhibit rapid transitions associated with nonlinear atmospheric dynamics
- respond to external forcings (e.g., ENSO or anthropogenic effects)

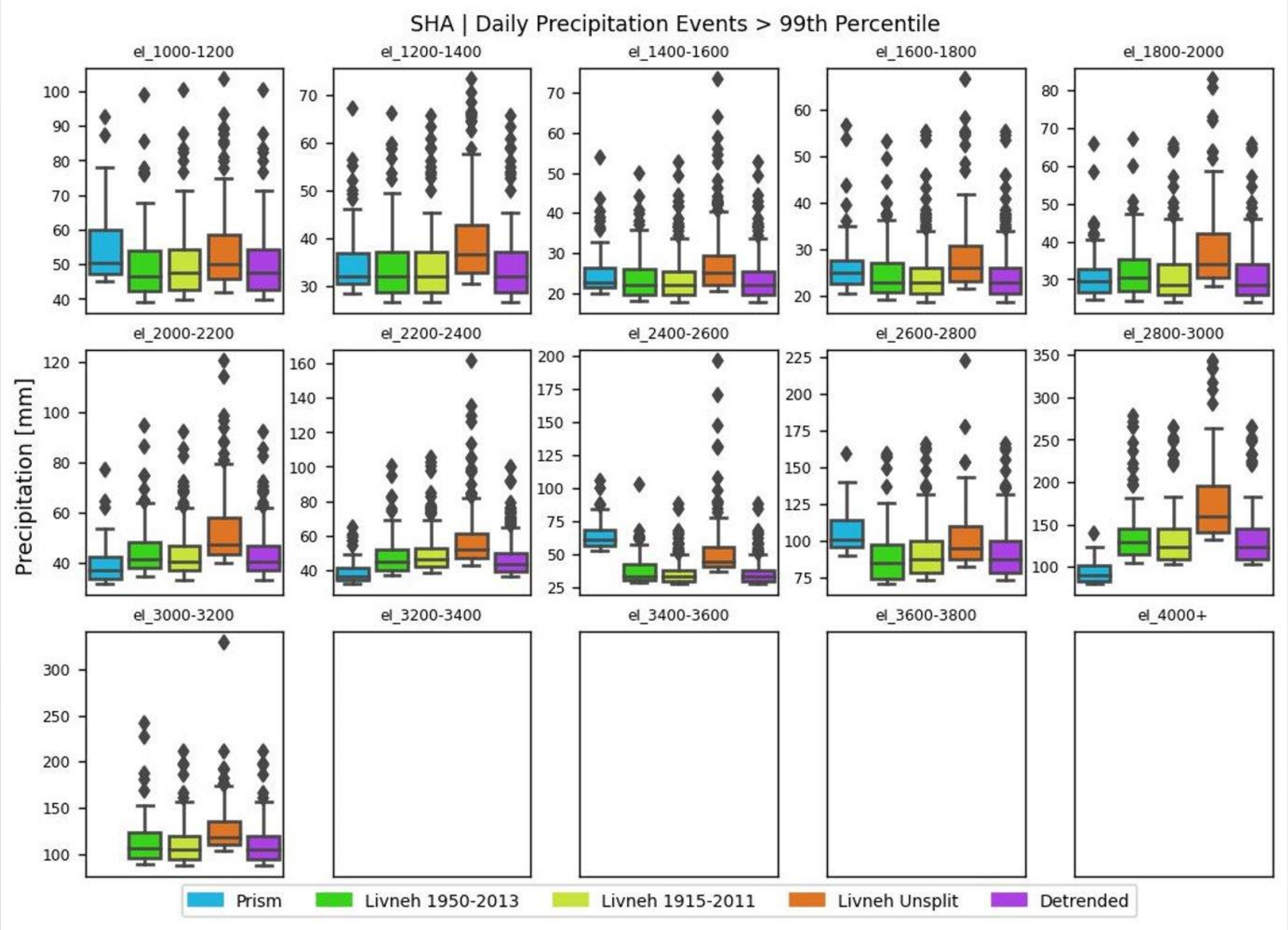
US Army Corps of Engineers
WATER & POWER
Cornell University
SCRIPPS INSTITUTION OF OCEANOGRAPHY
UC San Diego

Climatic Input and Perturbations



Climate data

- 1915-2018 daily 1/16th gridded composite
- **Temperature**: Livneh 1915-2015 that is bias-corrected and extended to PRISM (1915-2020) and temperature detrended (1991-2020)
- **Precipitation**: Livneh 1915-2018 "unsplit extreme preserving"



JULY 2021 PIERCE ET AL. 1883

An Extreme-Preserving Long-Term Gridded Daily Precipitation Dataset for the Conterminous United States

DAVID W. PIERCE,[a] LU SU,[b] DANIEL R. CAYAN,[a] MARK D. RISSER,[c] BEN LIVNEH,[d] AND DENNIS P. LETTENMAIER[b]

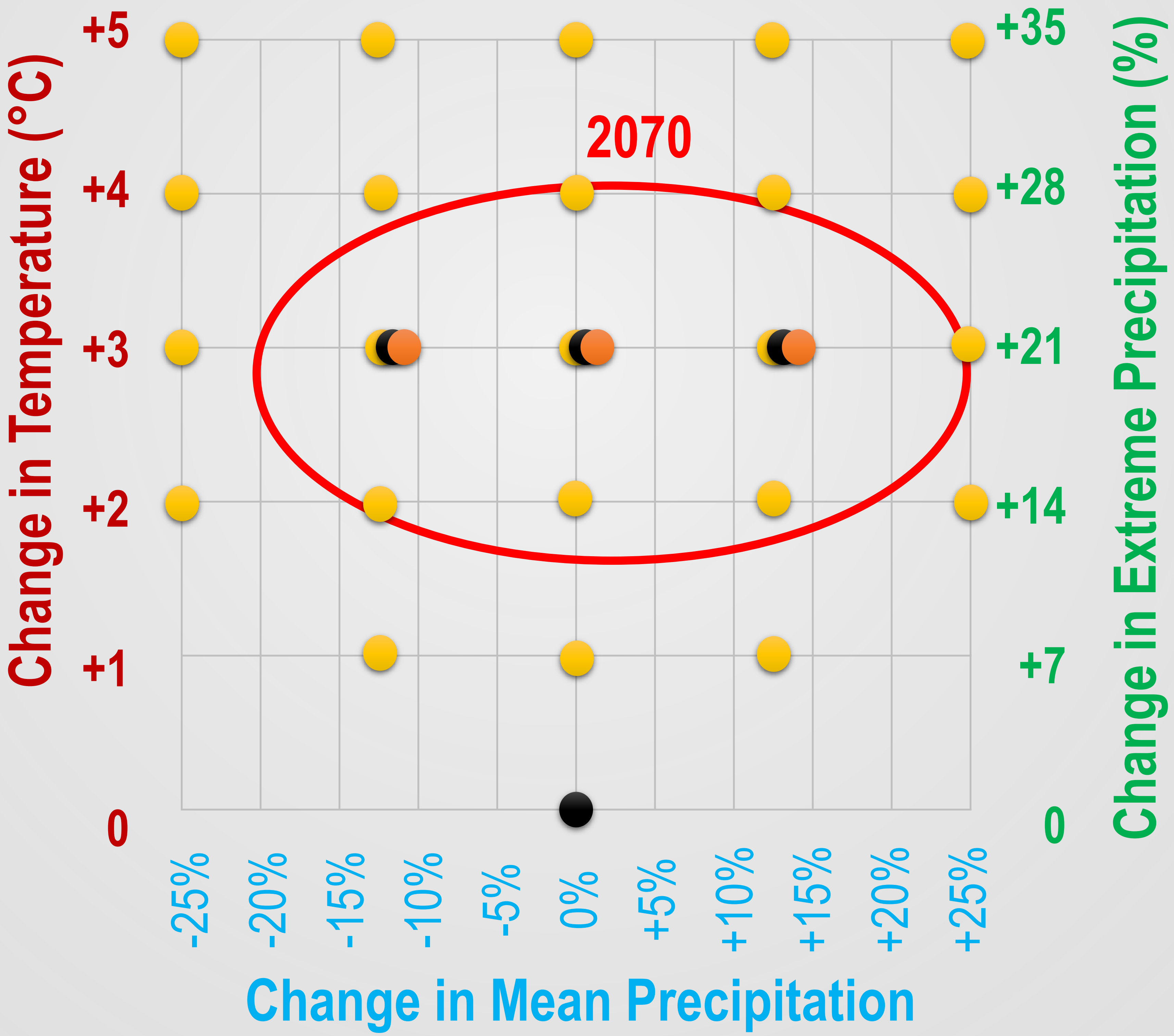
[a] *Climate, Atmospheric Sciences, and Physical Oceanography, Scripps Institution of Oceanography, La Jolla, California*
[b] *Department of Geography, University of California, Los Angeles, Los Angeles, California*
[c] *Lawrence Berkeley National Laboratory, Berkeley, California*
[d] *CIRES, University of Colorado Boulder, Boulder, Colorado*

Climate and Perturbations

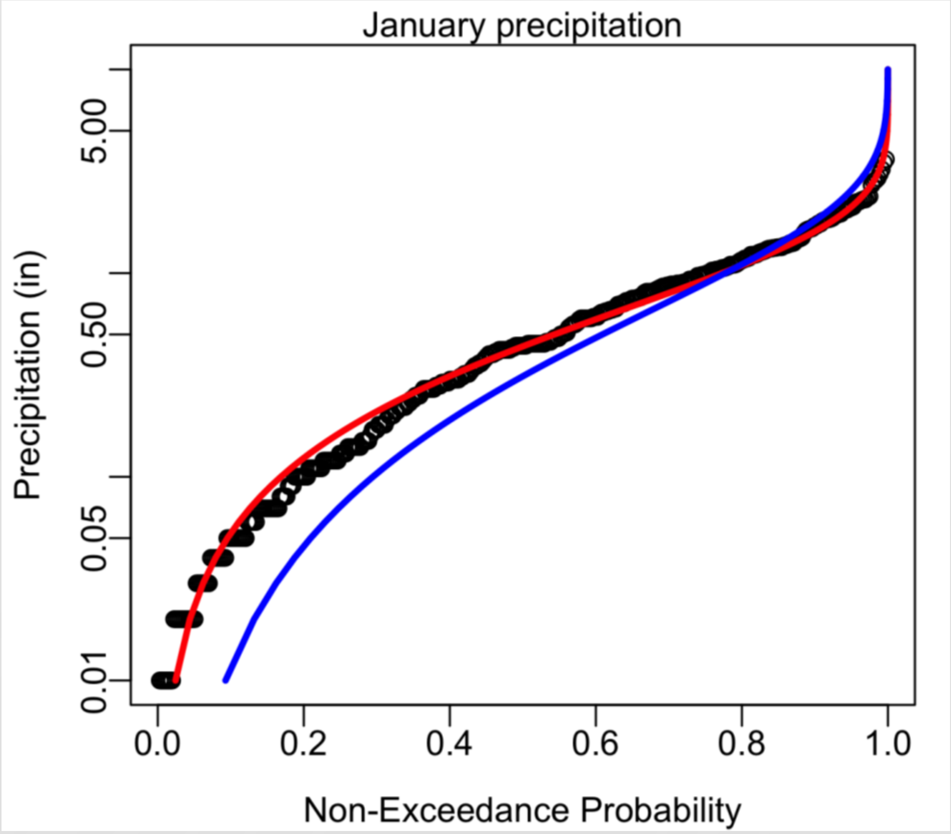
Perturbations

- Baseline (1915-2018)
- 0°C to +5°C
- -25% to +25% total precipitation
- +7%/°C Clausius-Clapeyron scaling

24+6 runs



Change in Extreme Precipitation:
+7% per °C
0% per °C
+14% per °C



Climate Change Analytical Approach

Temperature Comparison Increase (C°)

	Tuolumne River		
Event Duration	1-Day	3-Day	30-Day
Difference ARkFuture-ARkHistoric	**4.87**	**4.82**	**1.90**

CVFPP Climate Change Scenarios	Low	Median	High
1997	1.97	2.72	3.72
1986	2.02	2.72	3.78
1956	1.94	2.70	3.75
1951	2.36	3.23	4.64
Average	**2.07**	**2.84**	**3.97**

Weather Generator Temperature Increase: +1, +2, +3, +4 and +5

Precipitation Comparison

Event Duration	Tuolumne River Watershed 1-Day	3-Day	30-Day
ARkHistoric	91	199	748
Percentage Increase from ARkFuture	**103%**	**86%**	**60%**

CVFPP Climate Change Scenarios	Hist Value	Low	Median	High
1997	622	3%	18%	32%
1986	734	11%	18%	21%
1956	755	2%	0%	23%
1951	711	-5%	-8%	1%
Average		**3%**	**7%**	**20%**

Precipitation Comparison

Tuolumne River Watershed

1-Day

Temperature Change (C)	-25	-12.5	0	+12.5	+25
+5	39%	39%	40%	40%	40%
+4	30%	30%	31%	31%	31%
+3	22%	22%	22%	22%	23%
+2	14%	14%	14%	14%	15%
+1		7%	7%	7%	
0			0%		

Precipitation Change (%)

ARkStorm Approximate Return Flood

Don Pedro Return Period of Flood	1-Day	3-Day	30-Day
ARkHistoric	12-Yr	10-Yr	153-Yr
ARkFuture	280-Yr	310-Yr	43,000-Yr
Climate Change Factor	2.8	3.8	2.6

Oroville Return Period of Flood	1-Day	3-Day	30-Day
ARkHistoric	14-Yr	18-Yr	13-Yr
ARkFuture	104-Yr	70-Yr	2,900-Yr
Climate Change Factor	1.9	1.5	2.5

Return Period calculated based on Central Valley Hydrological Study / Bulletin 17C (2012)

$$\text{Climate Change Factor}_{\text{(n-day volume)}} = \frac{ARkFuture\ Peak\ Volume_{(n-day\ volume)}}{ARkHistoric\ Peak\ Volume_{(n-day\ volume)}}$$

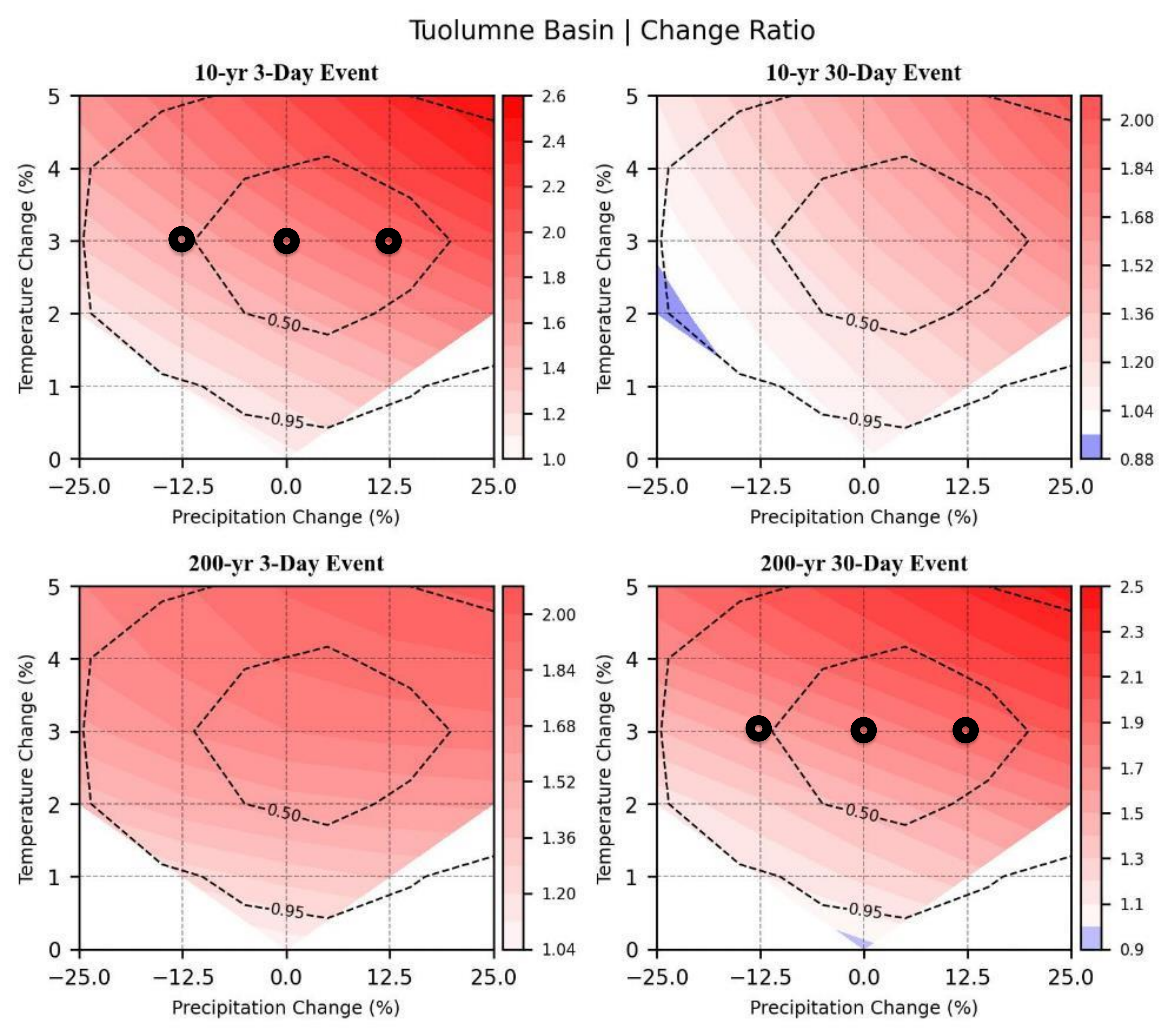
CVFPP Climate Change Factor

Tuolumne River Watershed

CVFPP Climate Change Scenarios	Low	Median	High
10-Yr, 3-Day Event	1.07	1.25	1.70
10-Yr, 30-Day Event	1.00	1.08	1.28
200-Yr, 3-Day Event	1.33	1.79	2.59
200-Yr, 30-Day Event	1.08	1.27	1.68

Don Pedro Return Period of Flood	3-Day	30-Day
ARkHistoric	10-Yr	153-Yr
Climate Change Factor	3.8	2.6

Weather Generator Perturbations Climate Change Factor



Don Pedro Return Period of Flood	3-Day	30-Day
ARkHistoric	10-Yr	153-Yr
Climate Change Factor	3.8	2.6

		Precipitation Change (%)		
		-12.5	0	12.5
Temperature Change: +3°C, 2CC	3-Day 10Yr	1.62	1.79	2.01
	30-Day 10Yr	1.41	1.27	1.46
	3-Day 200Yr	1.38	2.17	2.26
	30-Day 200Yr	1.61	1.88	2.04

Summary of Findings

- All approaches have a consistent increase in temperature.
- Extremes precipitation increases roughly by +3.9%/°F (+7%/°C) for daily precipitation above the 99% Prob.
- Unregulated flood flows will increase in the Central Valley.
- ARkHist has a surprisingly small return flood

Summary of Findings

- ARkFuture is increasing the 30-day peak flow by x2.5.
- CVFPP scenarios are increasing the Tuolumne River 30-day peak flow up to x1.7.
- WGEN perturbations are increasing the Tuolumne River 30-day peak flow from x1.0 to x2.4.

Summary of Findings

- ARkFuture should only be used for table-top exercises.
- CVFPP's climate change analysis shows a range of uncertainty and should be used for planning purposes,
- Weather Generator perturbations cover a large range of climate change conditions and are being applied more broadly in DWR activities.

Questions

Romain.Maendly@water.ca.gov

CVFPP Climate Change Factor

Tulumne River Watershed

CVFPP Climate Change Scenarios	Low	Median	High
10-Yr, 3-Day Event	1.07	1.25	1.70
10-Yr, 30-Day Event	1.00	1.08	1.28
200-Yr, 3-Day Event	1.33	1.79	2.59
200-Yr, 30-Day Event	1.08	1.27	1.68

Feather River Watershed

CVFPP Climate Change Scenarios	Low	Median	High
10-Yr, 3-Day Event	1.23	1.41	1.86
10-Yr, 30-Day Event	1.10	1.29	1.65
200-Yr, 3-Day Event	0.87	0.91	1.13
200-Yr, 30-Day Event	1.08	1.16	1.48

Don Pedro Return Period of Flood	3-Day	30-Day
ARkHistoric	10-Yr	153-Yr
Climate Change Factor	3.8	2.6

Oroville Return Period of Flood	3-Day	30-Day
ARkHistoric	18-Yr	13-Yr
Climate Change Factor	1.5	2.5