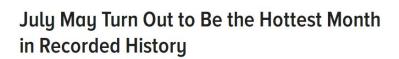
## **Regional Climate Change Conditions**

## **Context for Development of the Santa Margarita Groundwater Basin GSP**

December 11th, 2019 Meeting of the Santa Margarita Groundwater Agency GSA

(y)-(f)-(<)-



If this year's record-breaking trend continues, we're on track for 2015–2019 to be the hottest 5 years on record.



Balance Hydrologics, Inc.

CLIMATE CHANGE

P News

Shawn Chartrand, PhD, CEG Balance Hydrologics schartrand@balancehydro.com



# Why Does Climate Change Matter for SGMA and the Santa Margarita Basin GSP?



# Why Does Climate Change Matter for SGMA and the Santa Margarita Basin GSP?



Firefighters battle the Maria Fire in Santa Paula, California on November 1. AP PHOTO/NOAH BERGER

## Climate Whiplash: Wild Swings in Extreme Weather Are on the Rise

As the world warms, scientists say that abrupt shifts in weather patterns – droughts followed by severe floods, or sudden and unseasonable fluctuations in temperature – are intensifying, adding yet another climate-related threat that is already affecting humans and natural world.

BY JIM ROBBINS · NOVEMBER 14, 2019

f 🖌 🗠

From 2011 to 2016, California experienced five years of extreme drought, during which numerous high temperature records were broken. These hot, dry years were followed by the extremely wet winter of 2016 -2017, when, from October to March, an average of 31 inches of rain fell across the state, the second highest winter rainfall on record.



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# Climate change <u>is not a local issue</u>. It is a regional, state-wide & global issue.

There is no one that will come to the rescue in the face of climate change challenges

Climate change challenges are grand. <u>How</u> <u>do we plan and achieve groundwater</u> <u>sustainability and resiliency in the face of</u> <u>an uncertain future?</u>



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BY JIM ROBBINS · NOVEMBER 14, 2019

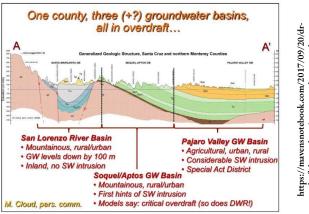
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Source: Yale E360

## Sustainable Groundwater Management Act

Groundwater is an important supply buffer during drought conditions



Source: Andy Fisher, UCSC

echarge-

ng-ground

-fisher-ei

vith

# Why Does Climate Change Matter for SGMA and the Santa Margarita Basin GSP?



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f 🎽 🗠

## Sustainable Groundwater Management Act

Groundwater is an important supply buffer during drought conditions

SGMA provides a framework that incentivizes the flexible management of groundwater aquifers because:

Source: Yale E360THE STATE RECOGNIZES THAT<br/>CLIMATE CHANGE WILL HAVESource: Yale E360SEVERE IMPACTS ON WATER SUPPLY



# **How Does SGMA Address Climate Change?**

## **Explicit Incorporation**

GSAs must incorporate quantitative climate change assessments into projected water budgets using a numerical groundwater and surface water model or an <u>equally effective</u> <u>method, tool, or analytical model</u> (23 California Code of Regulations (CCR) 23 §§ 345.18(c)(3) and 345.18(e))

## **Implicit Incorporation**

Climate change implicitly present in the definition of groundwater sustainability in the legislation, which requires groundwater management to be sustainable over a <u>50-year planning</u> <u>and implementation horizon</u> (California Water Code (CWC) § 10727.2(c))



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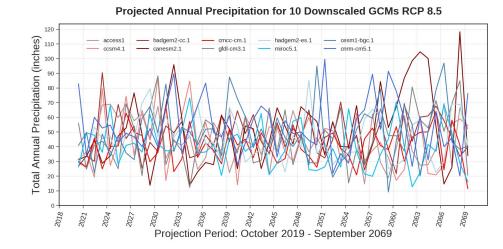
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How do we use climate change projections to identify GSP resource management strategies which can effectively address an uncertain future climate?



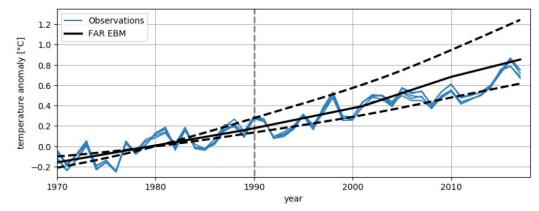
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## **How Does SGMA Address Climate Change?**



Source: Hausfather et al., 2019 GRL [December 4th accepted and published online]

## How do we use climate change projections to identify GSP resource management strategies which can effectively address an uncertain future climate?



# Part 1: Overview of Historical Climate Data

# Part 2: Overview of Modeling Plausible Future Streamflows

Fractional Change of Mean Precipitation



HISTORICAL OVERVIEW

## **Overview of Historical Climate Data**

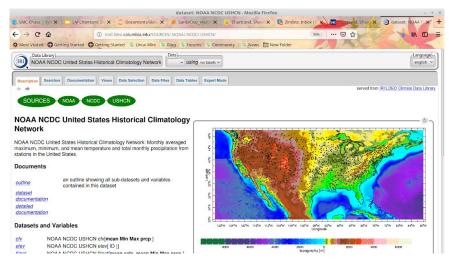
- **1. Precipitation trends**
- 2. Air temperature trends
- **3.** Basic conclusions and how historical climate trends links to our work



#### HISTORICAL CLIMATE Data

## Data Portals for Historical Data

## NOAA Historical Climatology S.C. 47916



#### Nov 1873 - Dec 1996 [Monthly]

## CIMIS De Laveaga #104 [UC IPM]

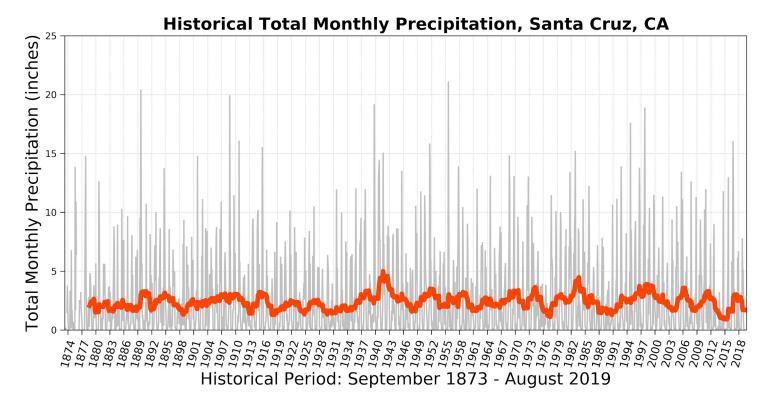
wn_chartrand@ 🗙 🎯 SMC-Cha	os   Syncthing 🗙 🚾 Shawn M. Chartrand 🛛 🗙 🦲 SM Chartran	Water Comr 🗙	🏹 Zimbra: Inbox (7585)	×	K D	escrip		Veather
° 🛈							•	
UC & IPN Statewide Integrated Pest			_					
номе	How to Manage Pests California Weather Data: Station Descri	otion						
SEARCH	Station news   About the database   Weather menu							
SEARCH	Description of SNTACRUZ.A (CIMIS #104, D	Laveaga)						
ON THIS SITE	I Data:	Daily ~ Averages						
What is IPM?	Network:		•					
Home & landscape pests	CIMIS — California Irrigation Management Information System							
Agricultural pests	Observer							
Natural environment pests	CITY OF SANTA CRUZ - DWR SAN JOAQUIN DISTRICT							
Exotic & invasive pests	Location							
Weed gallery	County: Santa Cruz Nearest City: Santa Cruz Latitude: 37 deg 0 min N Longitude: 122 deg 0 min W Eler	ation: 300 ft						
Natural enemies gallery	Station and site characteristics							
Weather, models & degree-days	Manufacturer/model: Campbell Scientific Inc. CR-10 ( or CR-1	0X)						
Pesticide information	Ground cover: Irrigated grass							
Research	Available data UC IPM database records begin/end: September 28, 1990	on-going						
Publications	Reporting interval: Daily	on going						
Events & training	Stored variables: Air Temperature, max/min: Daily max/min measured at 1.5 m (							
Links	Reference Evapotranspiration: Calculated from CIMIS hourly val Precipitation: Daily total measured in a 20 cm (8 in) diameter ga							
Glossarv	Relative Humidity, max/min: Daily max/min relative humidity m		(4.97.01)					

#### Jan 1990 - present [Daily]



## HISTORICAL CLIMATE Precipitation

What have we observed in the past 100 years+ in terms of the S.C. climate?





• 24-month moving average

**HISTORICAL CLIMATE** 

# We Can Learn More if we Detrend the Annual Data

## **Annual Total Precip**

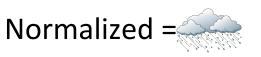


Long-term Annual Average Total Precip



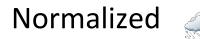
HISTORICAL CLIMATE

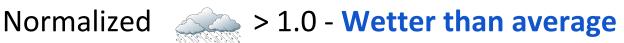
# We Can Learn More if we Detrend the Annual Data



## **Annual Total Precip**

Long-term Annual Average Total Precip









Normalized < 1.0 - Drier than average



## HISTORICAL CLIMATE Precipitation

140 Year Mean Precipitation = 28.7 inches Vormalized Annual Precipitation 2 -2 -Wetter than average **Drier than average** 883 988 2003 2006 1994 1997 œ ဖ σ œ C ア N 2-year moving average 5-year moving average 10-year moving average

## Normalized Total Annual Precipitation, Santa Cruz, CA

What have we observed in the past 100 years+ in terms of the S.C. climate?

Balance

rologics. Inc.

## HISTORICAL CLIMATE Precipitation

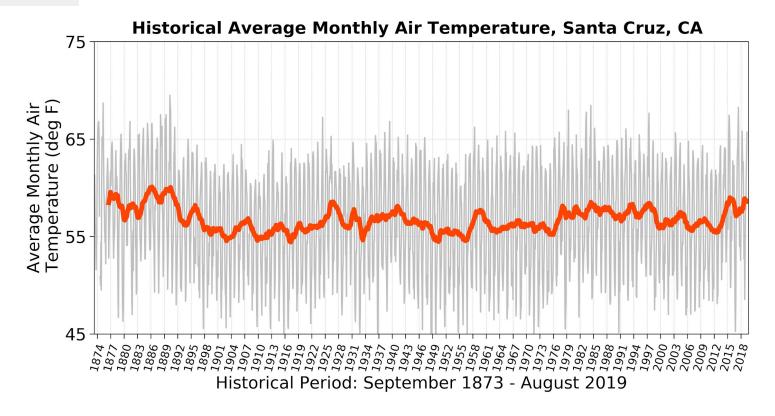
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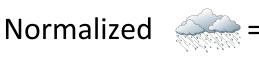




24-month moving average

HISTORICAL CLIMATE

# We Can Learn More if we Detrend the Annual Data



## Average Annual Air Temp

Long-term Annual Average Air Temp

Normalized > 1.0 - Hotter than average





## HISTORICAL CLIMATE Avg. Air Temp

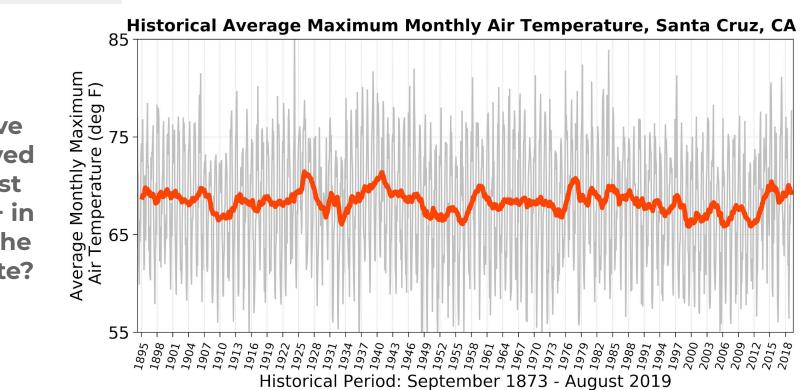
1.1 140 Year Mean Annual Air Temperature = 56.7 degrees Fahrenheit Air Temperature Normalized Average Warmer than average **Cooler than average** 0.9 883 886 889 889 892 œ N 2-year moving average 5-year moving average - 10-year moving average

## Normalized Average Annual Air Temperature, Santa Cruz, CA

What have we observed in the past 100 years+ in terms of the S.C. climate?



### HISTORICAL CLIMATE Max Air Temp



What have we observed in the past 100 years+ in terms of the S.C. climate?



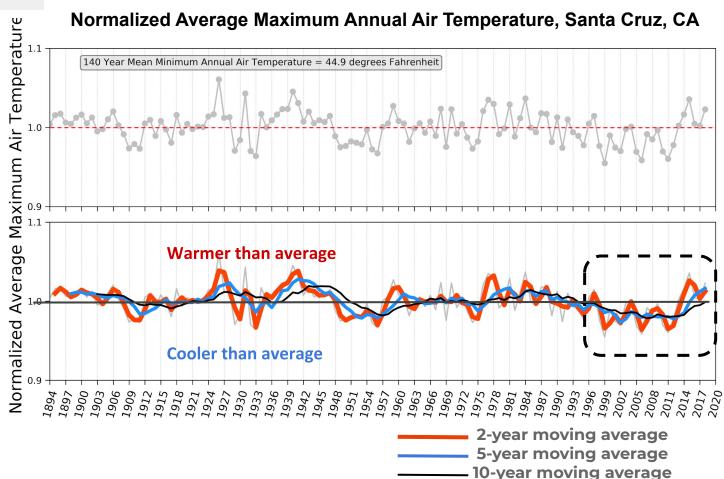
24-month moving average

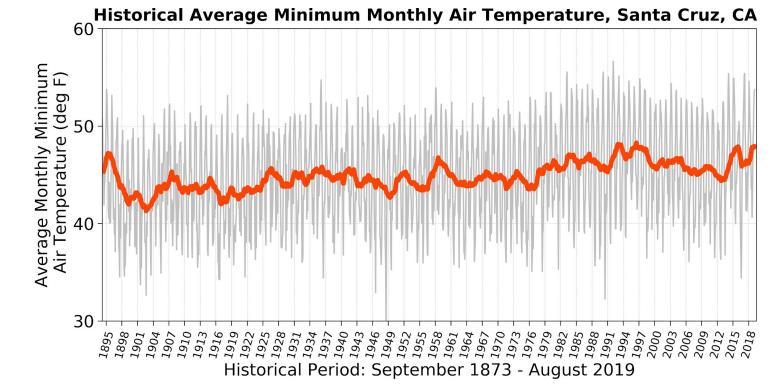
## HISTORICAL CLIMATE Max Air Temp

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Balance

rologics. Inc.





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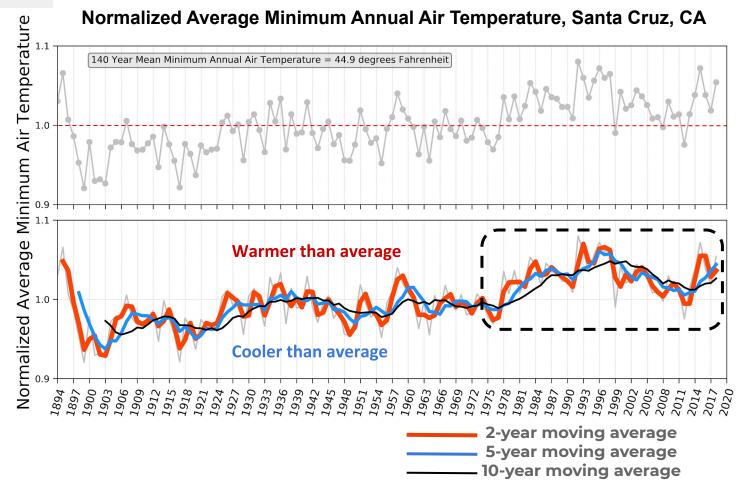
24-month moving average

## HISTORICAL CLIMATE Min Air Temp

What have we observed in the past 100 years+ in terms of the S.C. climate?

Balance

drologics. Inc.



- Regularity of multi-year swings of precipitation has increased - WY12-15 drought is historically severe
- Mean air temperatures of recent 35 years historically warm
- Maximum air temperature shows an increasing trend over the past 7 yrs.
- Minimum air temperatures of recent 35 years historically warm



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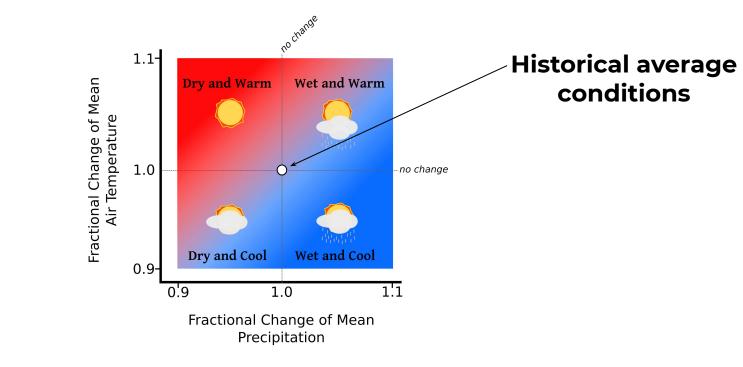
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## Why are We Spending Time on Historical Climate When Our Focus is Planning for Projected Climate Change Conditions?

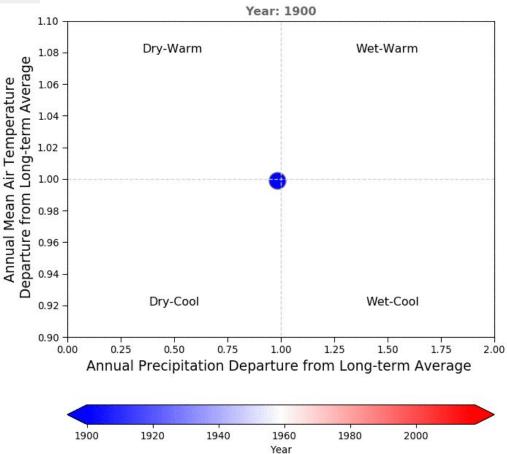






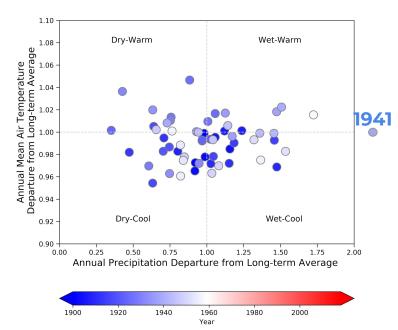


#### HISTORICAL CLIMATE Deeper Look



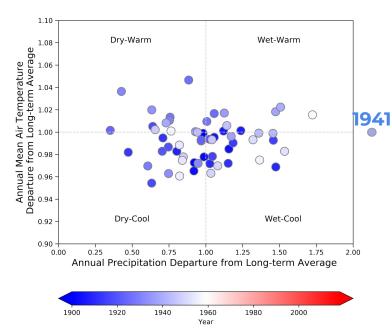


## 1900-1958

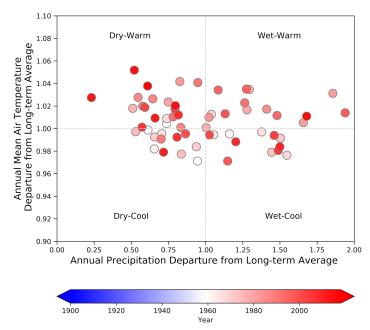




1900-1958



## 1959-2018

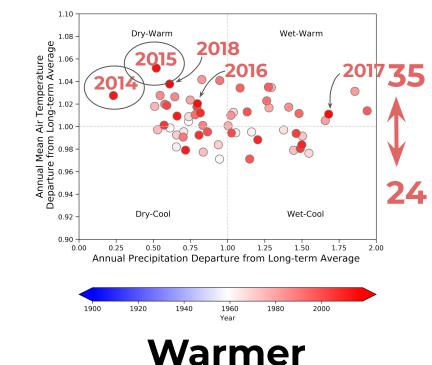


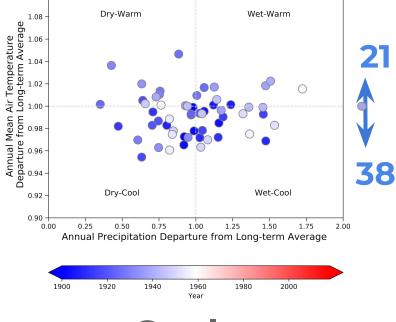


1.10

1900-1958



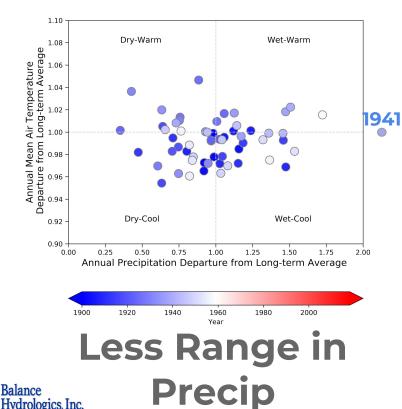




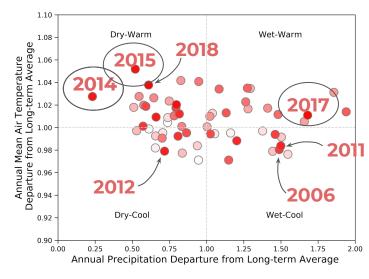
Cooler

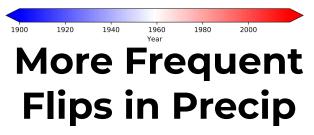


1900-1958









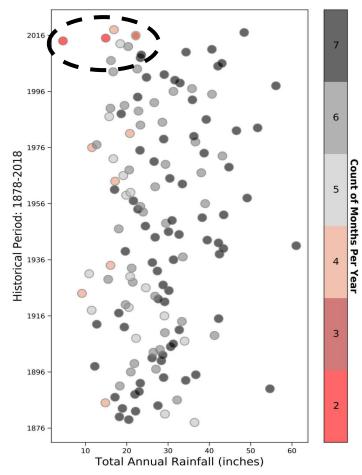
HISTORICAL CLIMATE Deeper Look

## Runoff producing rainfall recorded in fewer months of the year

[and we know those months are also warmer than average]

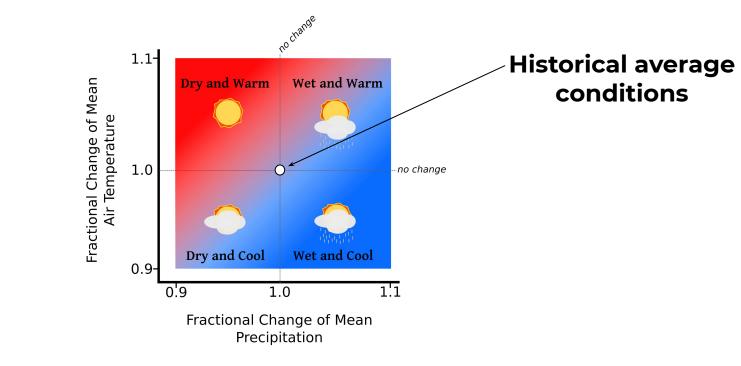


More than 0.5-inches of Rainfall



HISTORICAL CLIMATE Deeper Look

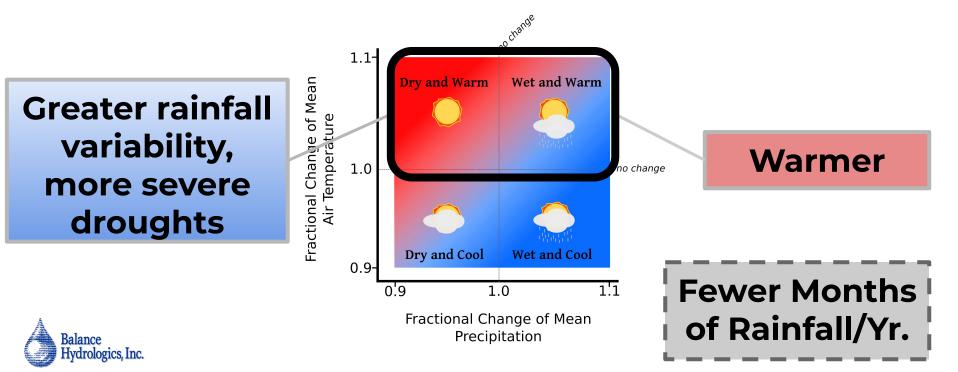
## How the Historical Climate Links to Our Climate Change Work





HISTORICAL CLIMATE Deeper Look

## How the Historical Climate Links to Our Climate Change Work



### **PROJECTED CLIMATE**

How Does the **Historical Climate** Trends Relate to **Projected Climate Change Conditions?** 



### Wetter, Drier, or Both?

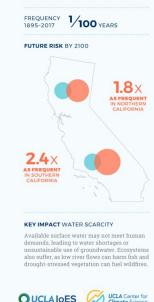
**INCREASING PRECIPITATION EXTREMES IN CALIFORNIA** 

California's climate has always featured wide swings between drought and flood. But in a warming world, precipitation will likely become even more volatile - with large increases in the frequency of extreme wet events, extreme dry events, and rapid transitions between them. These changes will pose major challenges for water, fire, and emergency management in 21st-century California.

#### Like: 2014 and 2015

#### Extreme **Dry Years**

Low November-March precipitation totals for these years resemble 2013-14 or 1976-77, the driest year in modern California history.

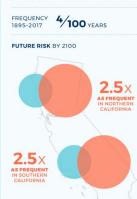


**Climate** Science

#### 1998 and 2017

#### Extreme Wet Years

In these years, the November-March period is as wet as in 2016–17, when statewide precipitation was 54% greater than average.



#### **KEY IMPACT INFRASTRUCTURE STRESS**

Runoff from heavy rains can stress levees, dams, and other flood control structures. Warmer temperatures amplify this effect by causing more precipitation to fall as rain. which immediately flows into rivers and streams, instead of snow.

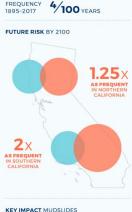
#### ©2018 UCLA Center for Climate Science

#### 2017 to 2018 Drv-to-Wet

Whiplash

FREQUENCY

This scenario represents the transition from a very dry year to a very wet one, as occurred between 2015-16 and 2016-17.



Although a very wet year following a drought can boost water supplies, a sudden transition from dry to wet conditions can cause its own problems. For example, heavy rains can result in mudslides and debris flows, especially near recent wildfire burn scars.

#### 1998 and 2017 Severe Storm

#### Sequence

In this scenario, 40-day precipitation totals are similar to those during California's "Great Flood of 1862."





#### KEY IMPACT CATASTROPHIC FLOODING

Such an event would cause inundation of a magnitude not experienced in modern California. The Great Flood of 1862 flooded much of the Central Valley and swaths of Los Angeles and Orange Counties now home to millions of people.

Find more on this project; www.ioes.ucla.edu/project/future-extreme-precipitation-california

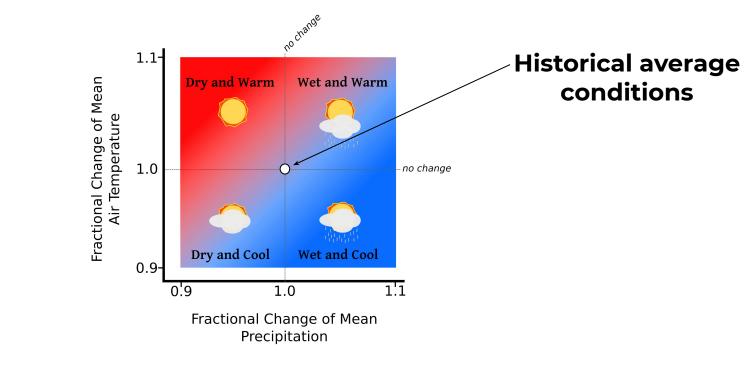
Source: https://www.ioes.ucla.edu/article/study-forecasts-a-severe-climate-future-for-california/

## **Overview of Modeling Plausible Future Streamflows**

- **1. General Strategy**
- 2. Limitations and Assumptions
- **3. Projected Climate Conditions Evaluated with the Hydrology Model**

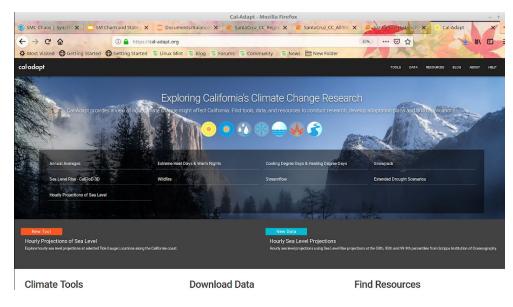


### Use a Simple Framework to Understand Projections of Climate





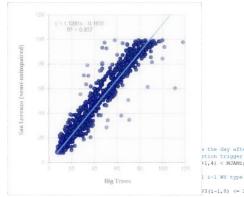
## Use a Public-domain CC Data to Develop Projections of Streamflow





### https://cal-adapt.org

## Use an Empirical-based Model to Develop Projections of Streamflow



v the day after is less than the
ation trigger
+1,4) < MJAMig(1,1)</pre>

l i-1 WY type is dry or drier and cell i is  $\pmb{\kappa}$ 

P3(1-1,8) <= 2 && MJAHCP3(1,8) >= 3

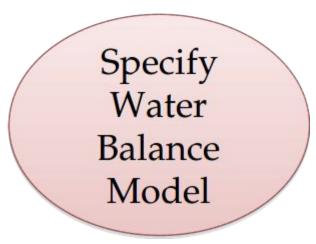
% This series of operations/queries will % compute the vector length of flows that % exceed some threshold from the last value % above the threshold. This is used to % accumulate counts against a counter that % begins if the hydrologic condition % changes as queried above. less = l3:-1:1; z = langth(less); flow = MXRCP3(1-less,4); flow = MXRCP3(1-less,4); flowgreates] = find(flow > MXRMig(l,1)); numberofvalues = length(flowgreater); last = max(flowgreater);

if numberofvalues >= 2

MJAHCP3(1,6) = 201 + (z - last); MJAHCP2(1,7) = MJAMig(1,2); MJAHCP3(1,7) = MJAMig(1,2);



## Use an Empirical-based Model to Develop Projections of Streamflow



Q = P - ET - R + B(CoS)

**Q: Streamflow** 

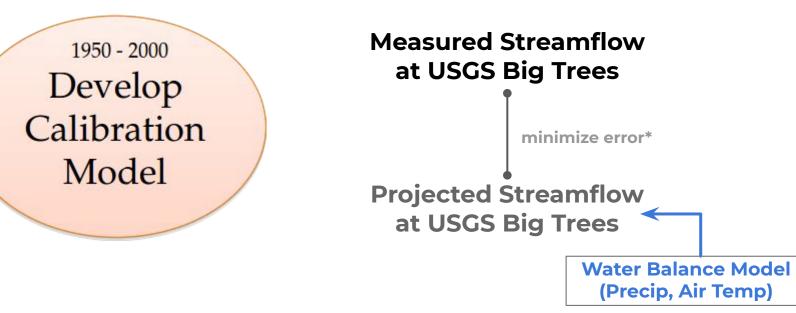
**P: Precipitation** 

ET: Evapotranspiration (Air Temp)

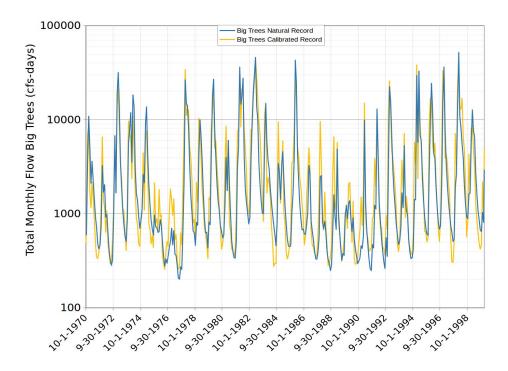
R: Recharge\*

**B: Baseflow\*** 



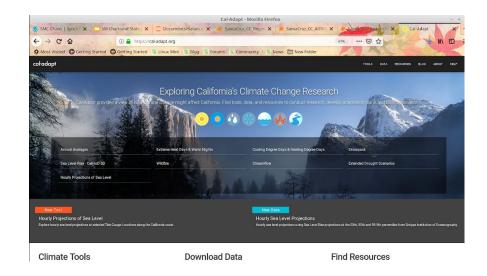




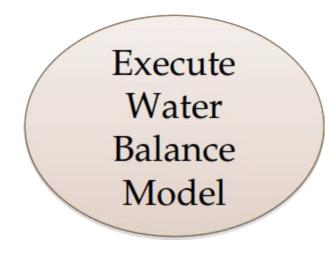


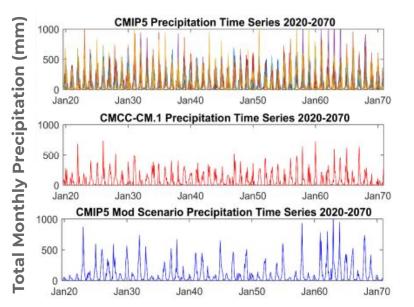








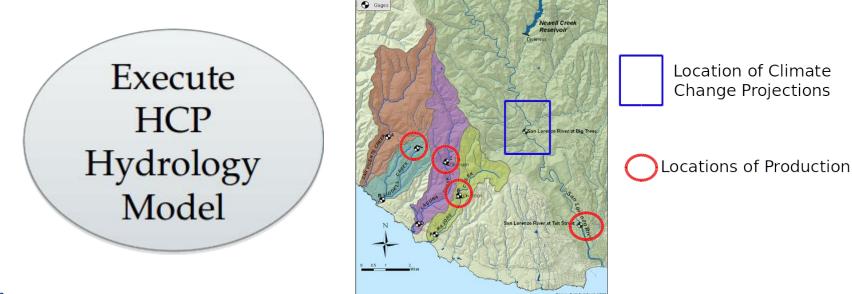






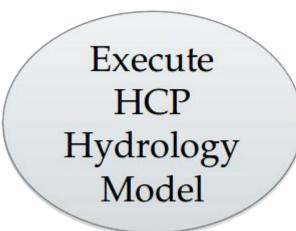
## Use an Empirical-based Model to Develop Projections of Streamflow

Legend





## Use an Empirical-based Model to Develop Projections of Streamflow





## **Partition Streamflow**

FLOW RULES





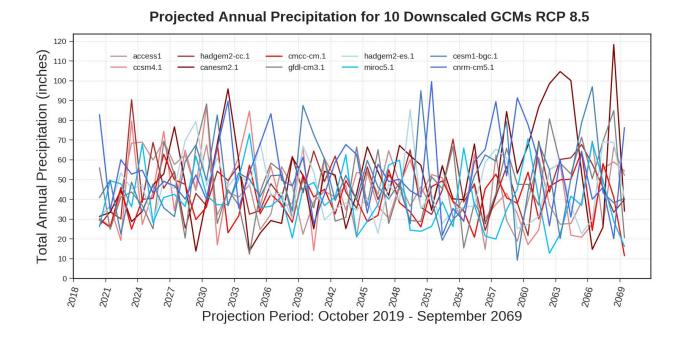
water supply

instream flows

### PROJECTED CLIMATE Limitations and Assumptions

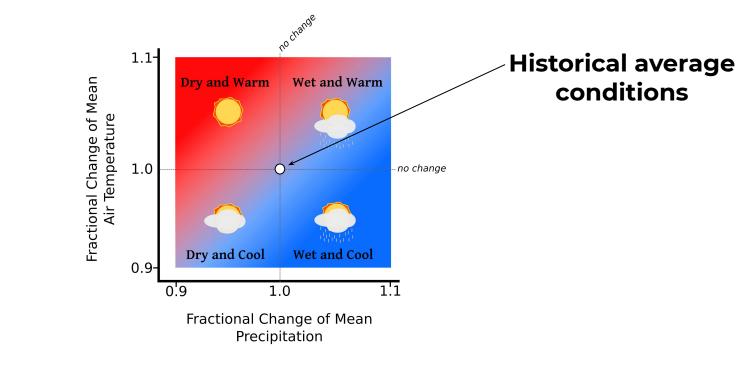
- 1. We use a simple hydrologic modeling framework which assumes:
  - a. present-day controls on runoff will persist as the climate changes [e.g. proportion of recharge vs. runoff, rainfall intensity. Etc.].
  - b. Present-day flow covariation between Big Trees and the Coast will persist as the climate changes.
- 2. Water balance model limited to "average" flow conditions at Big Trees, i.e. wet and dry flows could be more severe than projected.
- 3. Mean daily projected flows assume day-to-day flow patterns will be similar to observed historical conditions for comparable overall hydrologic conditions.
- 4. We are not using State projected flow conditions at Big Trees Balance Hydrologics, Inc.

## Use a Simple Framework to Understand Projections of Climate

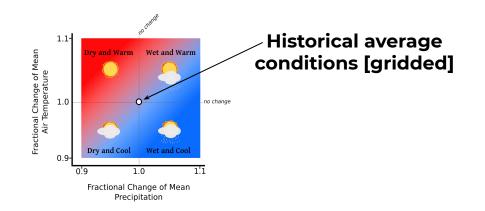




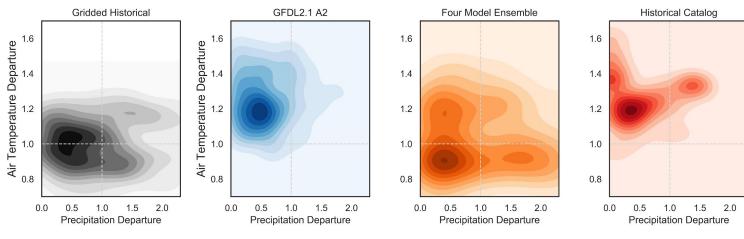
### Use a Simple Framework to Understand Projections of Climate







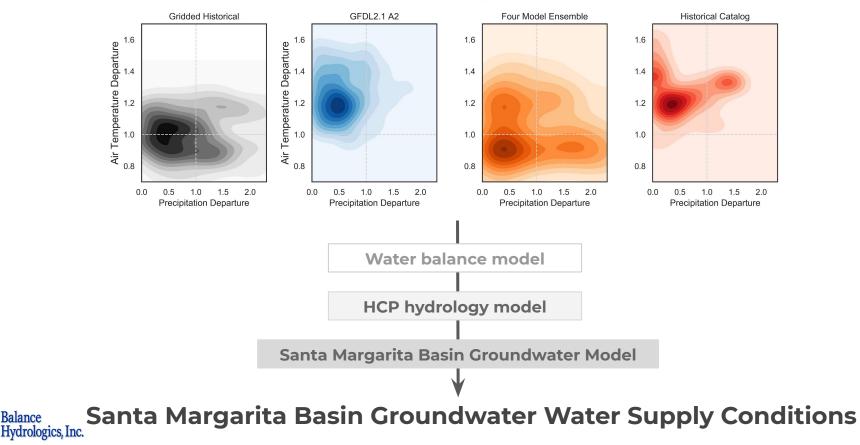
#### Probability Density Estimates of Winter Monthly Departure for Climate Change Projections



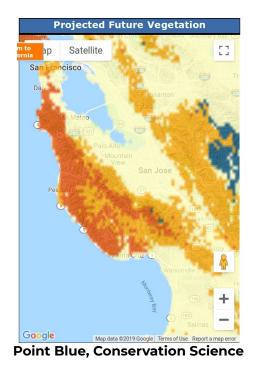
Balance Hydrologics, Inc.

Time Period: 2020-2070

Balance



#### **Probability Density Estimates of Winter Monthly Departure** for Climate Change Projections



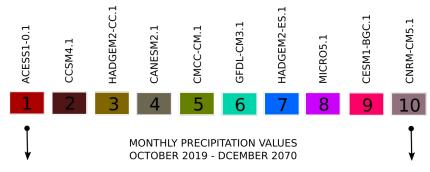
alance

## What We Learn from Climate Projections at Santa Cruz

- Hotter and overall drier is likely, punctuated by greater frequency of large storms
- Steelhead and coho salmon will be stressed relative to historical conditions
- Water supply will be stressed more severely relative to historical conditions
- Missing pieces of climate planning: Coastal fog persistence? Vegetative communities shift? Forest fire frequency?

### INTRODUCTION

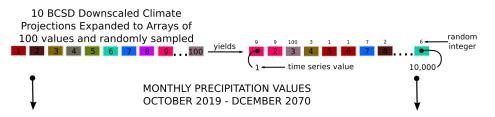
#### 10 BCSD Downscaled Climate Projections



#### STOCHASTIC MODELING STEPS

1. For each month in the time series from October 2019-December 2070 and across all 10 climate projections, create a new monthly array of 100 precipitation values in the range defined by the monthly minimum and maximum precipitation. This step aligns with the assumption that the 10 projections capture the expected monthly range of precipitation values under future conditions.

2. Use a random integer in the range 1 to 100 to sample the 100 projections 10,000 times for each month in the time series to build a projection ensemble of 10,000 future possible precipitation records. Each record has the same probability of occurrence.



# **QUESTIONS?**

