Regional Climate Change Conditions

Context for Development of the Santa Margarita Groundwater Basin GSP

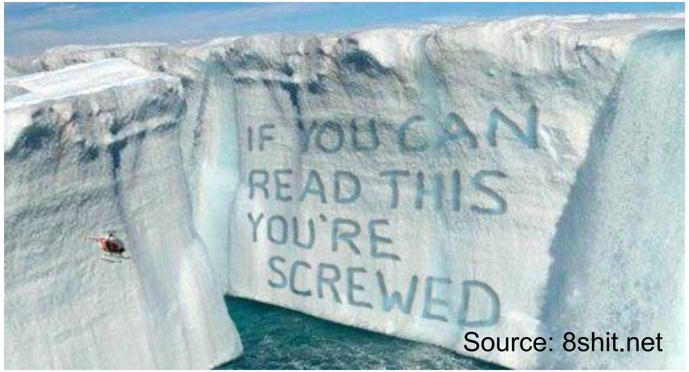
December 11th, 2019 Meeting of the Santa Margarita Groundwater Agency GSA

CLIMATE CHANGE News

July May Turn Out to Be the Hottest Month in Recorded History

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

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



Source: 8shit.net

Balance Hydrologics, Inc.

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

Source: Yale E360

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.

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

Source: Yale E360

Climate change is not a local issue. 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. How do we plan and achieve groundwater sustainability and resiliency in the face of an uncertain future?

Balance Hydrologics, Inc.

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

Source: Yale E360

Climate change is not a local issue. 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. How do we plan and achieve groundwater sustainability and resiliency in the face of an uncertain future?

Balance Hydrologics, Inc.

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

Source: Yale E360

Climate change is not a local issue. 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. How do we plan and achieve groundwater sustainability and resiliency in the face of an uncertain future?

Balance Hydrologics, Inc.

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

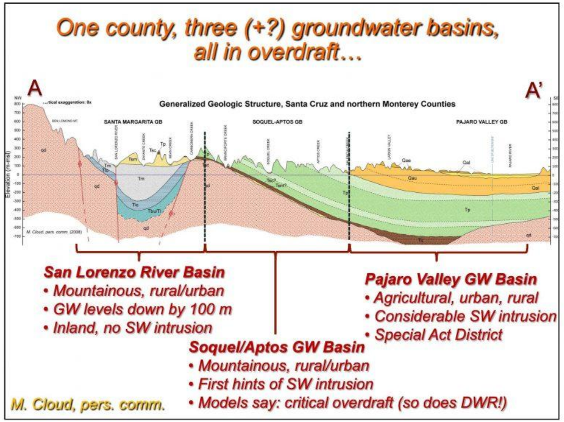
As the world warms, scientists say that abrupt shifts in weather patterns – droughts followed by severe floods, or sudden and unseasonable fluctuations in temperature – are intensifying, adding yet another climate-related threat that is already affecting humans and natural world.

BY JIM ROBBINS · NOVEMBER 14, 2019

Source: Yale E360

Sustainable Groundwater Management Act

Groundwater is an important supply buffer during drought conditions



Source: Andy Fisher, UCSC

https://mavensnotebook.com/2017/09/20/dr-andy-fisher-enhancing-groundwater-recharge-with-stormwater/

Balance Hydrologics, Inc.

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

Source: Yale E360

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:

THE STATE RECOGNIZES THAT CLIMATE CHANGE WILL HAVE SEVERE IMPACTS ON WATER SUPPLY

Balance Hydrologics, Inc.

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 equally effective method, tool, or analytical model (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 50-year planning and implementation horizon (California Water Code (CWC) § 10727.2(c))

Balance Hydrologics, Inc.

How Does SGMA Address Climate Change?

Explicit Incorporation

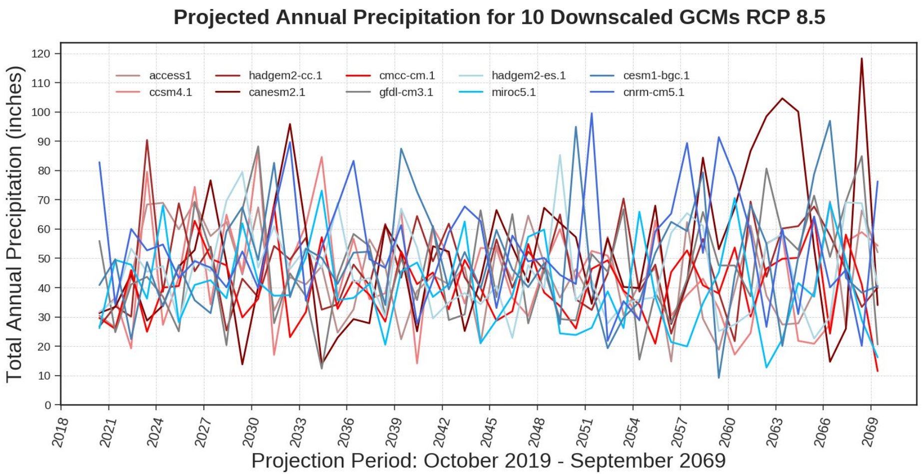
GSAs must incorporate quantitative climate change assessments into projected water budgets using a numerical groundwater and surface water model or an equally effective method, tool, or analytical model
(23 California Code of Regulations (CCR) 23 §§ 345.18(c)(3) and 345.18(e))

Implicit Incorporation

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

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

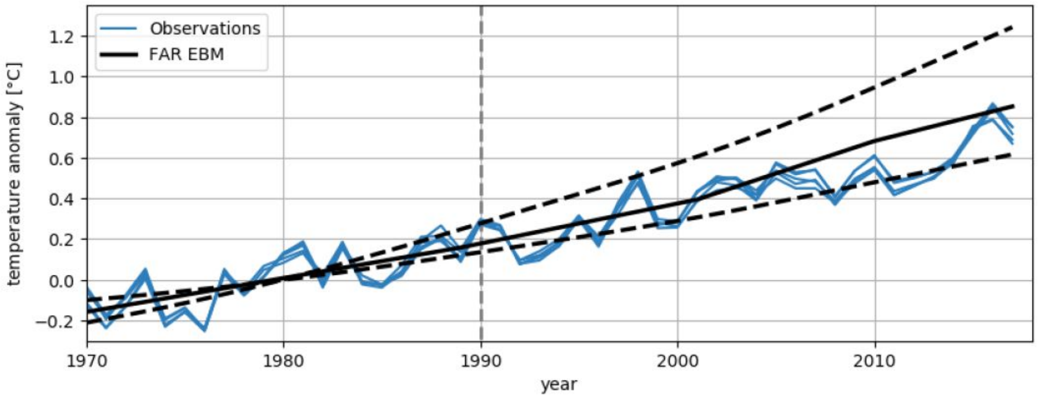
How Does SGMA Address Climate Change?



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

Balance Hydrologics, Inc.

How Does SGMA Address Climate Change?



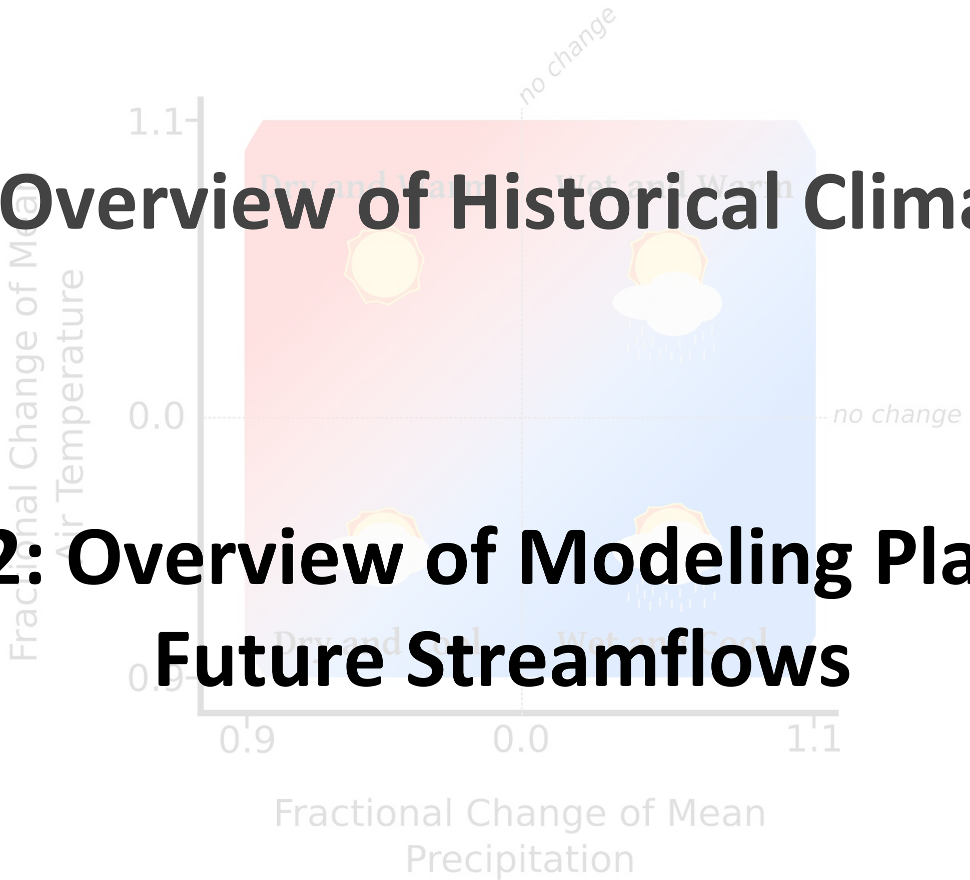
Source: Hausfather et al., 2019 GRL [December 4th accepted and published online]

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

Balance Hydrologics, Inc.

Part 1: Overview of Historical Climate Data

Part 2: Overview of Modeling Plausible Future Streamflows



Balance Hydrologics, Inc.

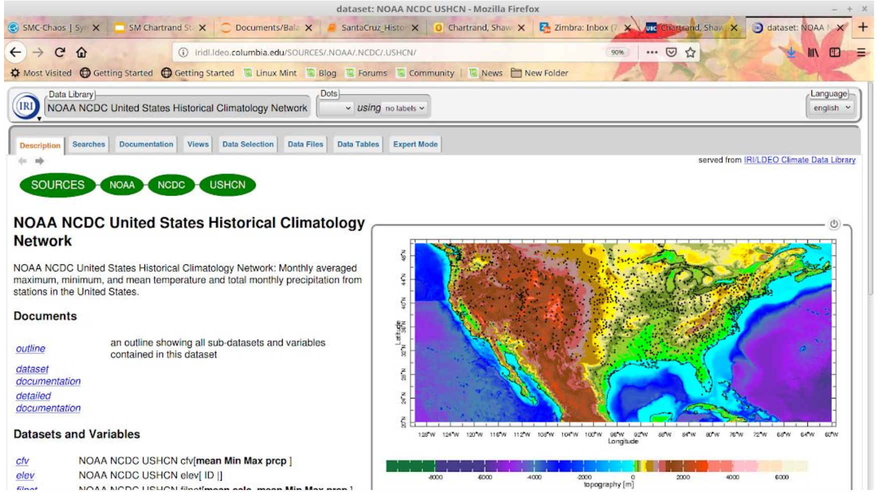
Overview of Historical Climate Data

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

Balance Hydrologics, Inc.

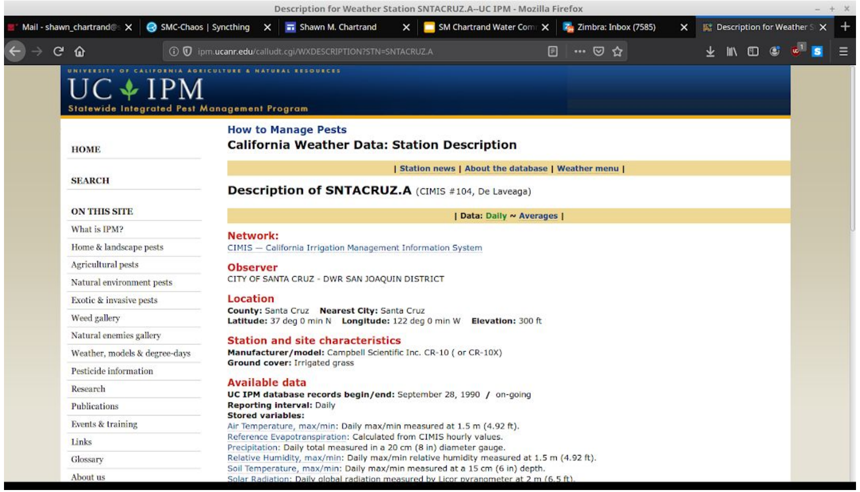
Data Portals for Historical Data

NOAA Historical Climatology S.C. 47916



Nov 1873 - Dec 1996 [Monthly]

CIMIS De Laveaga #104 [UC IPM]

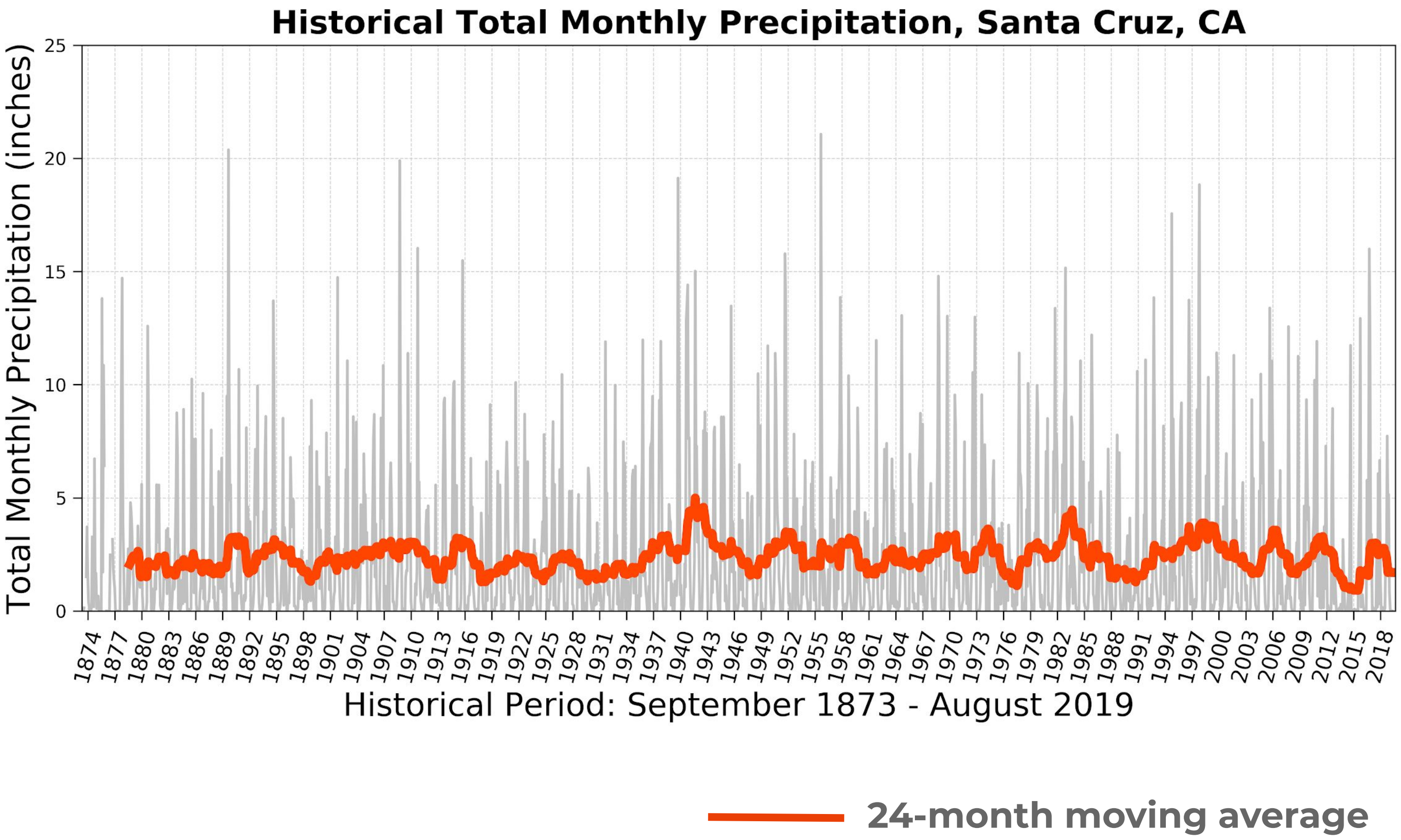


Jan 1990 - present [Daily]

Balance Hydrologics, Inc.

HISTORICAL CLIMATE
Precipitation

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



Balance Hydrologics, Inc.

We Can Learn More if we Detrend the Annual Data

$$\text{Normalized} = \frac{\textbf{Annual Total Precip}}{\textbf{Long-term Annual Average Total Precip}}$$

We Can Learn More if we Detrend the Annual Data

Normalized = $\dfrac{\textbf{Annual Total Precip}}{\textbf{Long-term Annual Average Total Precip}}$

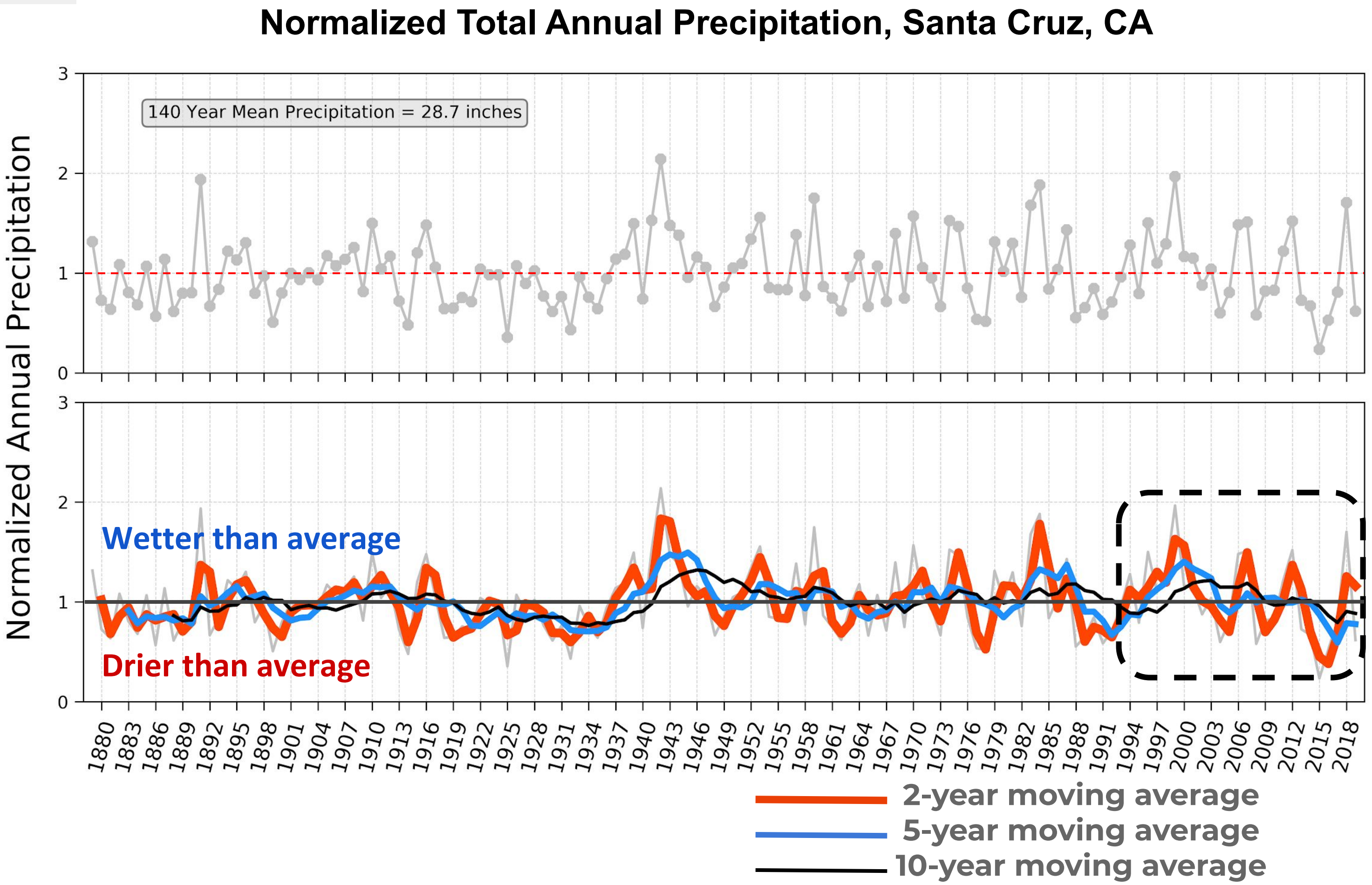
Normalized > 1.0 - **Wetter than average**

Normalized < 1.0 - **Drier than average**

Balance Hydrologics, Inc.

HISTORICAL CLIMATE
Precipitation

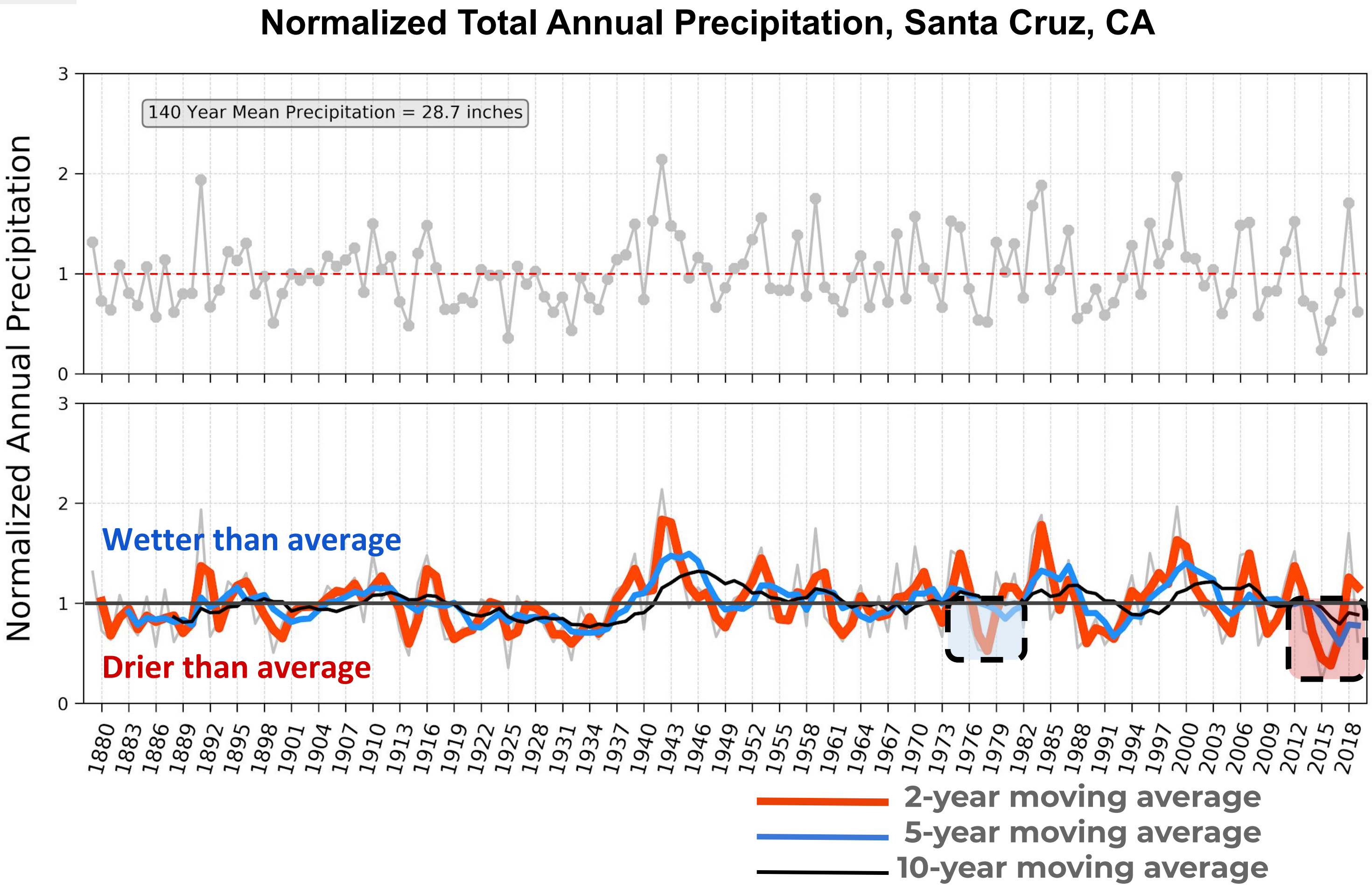
What have we observed in the past 100 years+ in terms of the S.C. climate?



Balance Hydrologics, Inc.

HISTORICAL CLIMATE
Precipitation

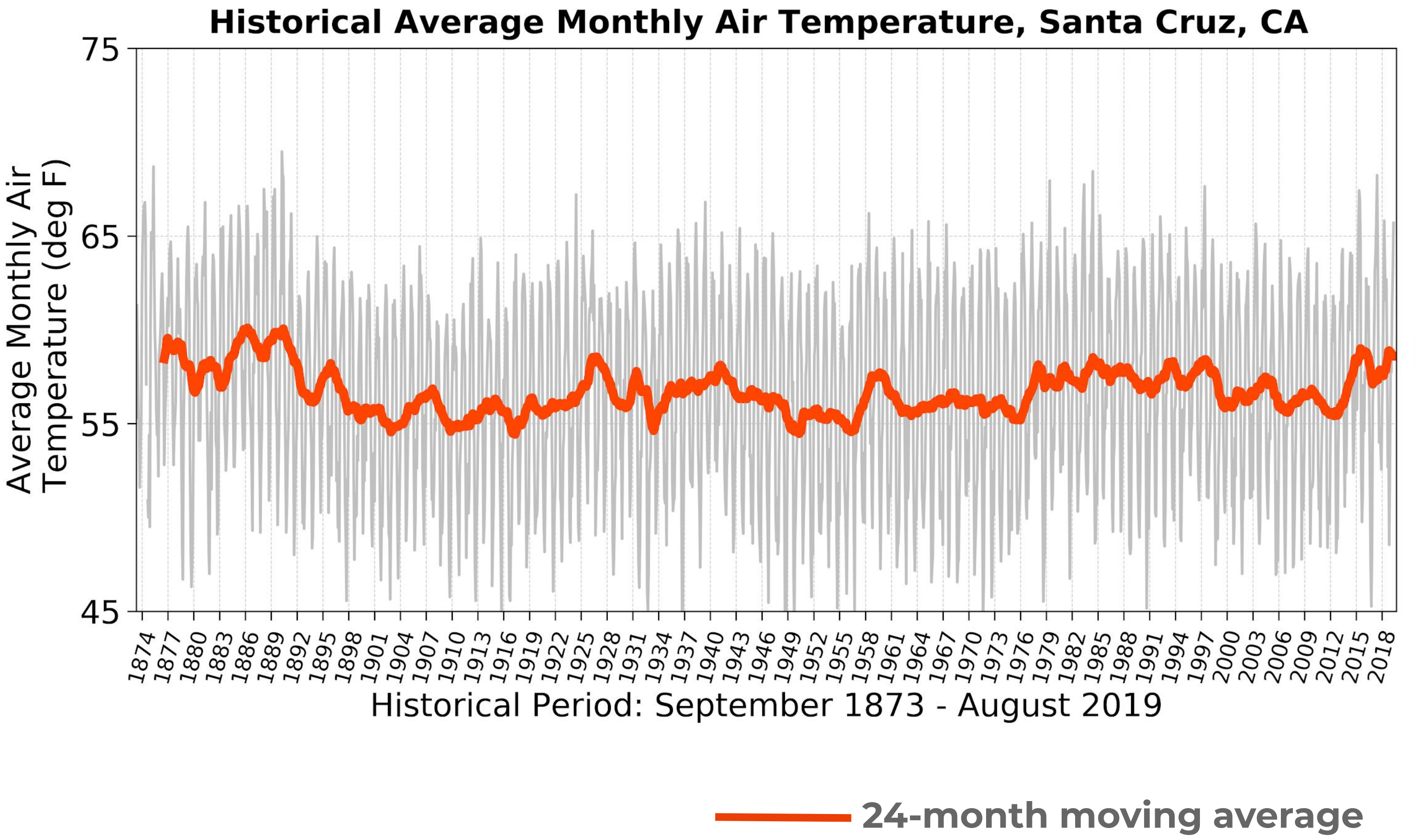
What have we observed in the past 100 years+ in terms of the S.C. climate?



Balance Hydrologics, Inc.

HISTORICAL CLIMATE
Avg. Air Temp

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



Balance Hydrologics, Inc.

We Can Learn More if we Detrend the Annual Data

Normalized  = $\dfrac{\textbf{Average Annual Air Temp}}{\textbf{Long-term Annual Average Air Temp}}$

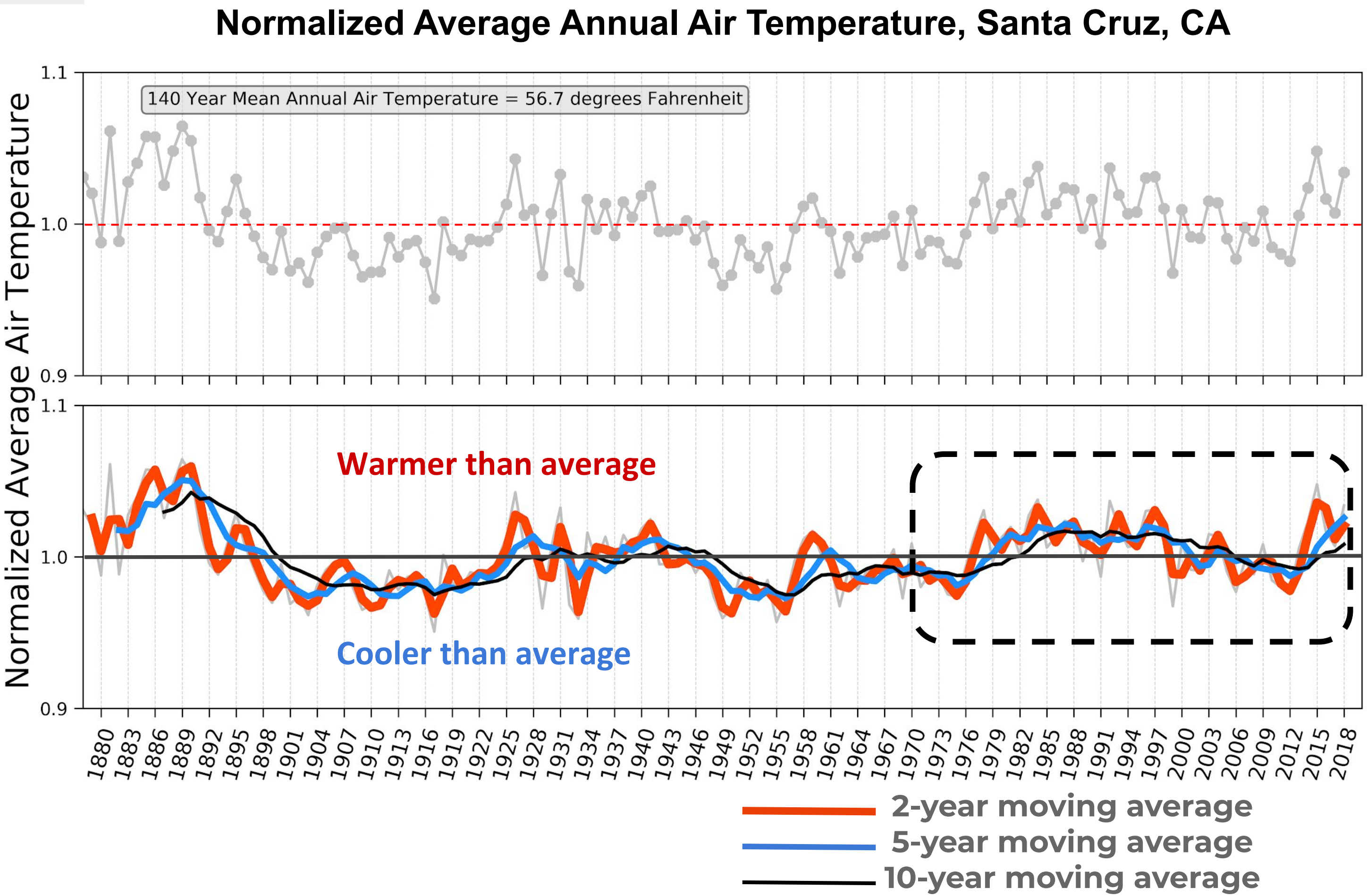
Normalized  > 1.0 - **Hotter than average**

Normalized  < 1.0 - **Cooler than average**

Balance Hydrologics, Inc.

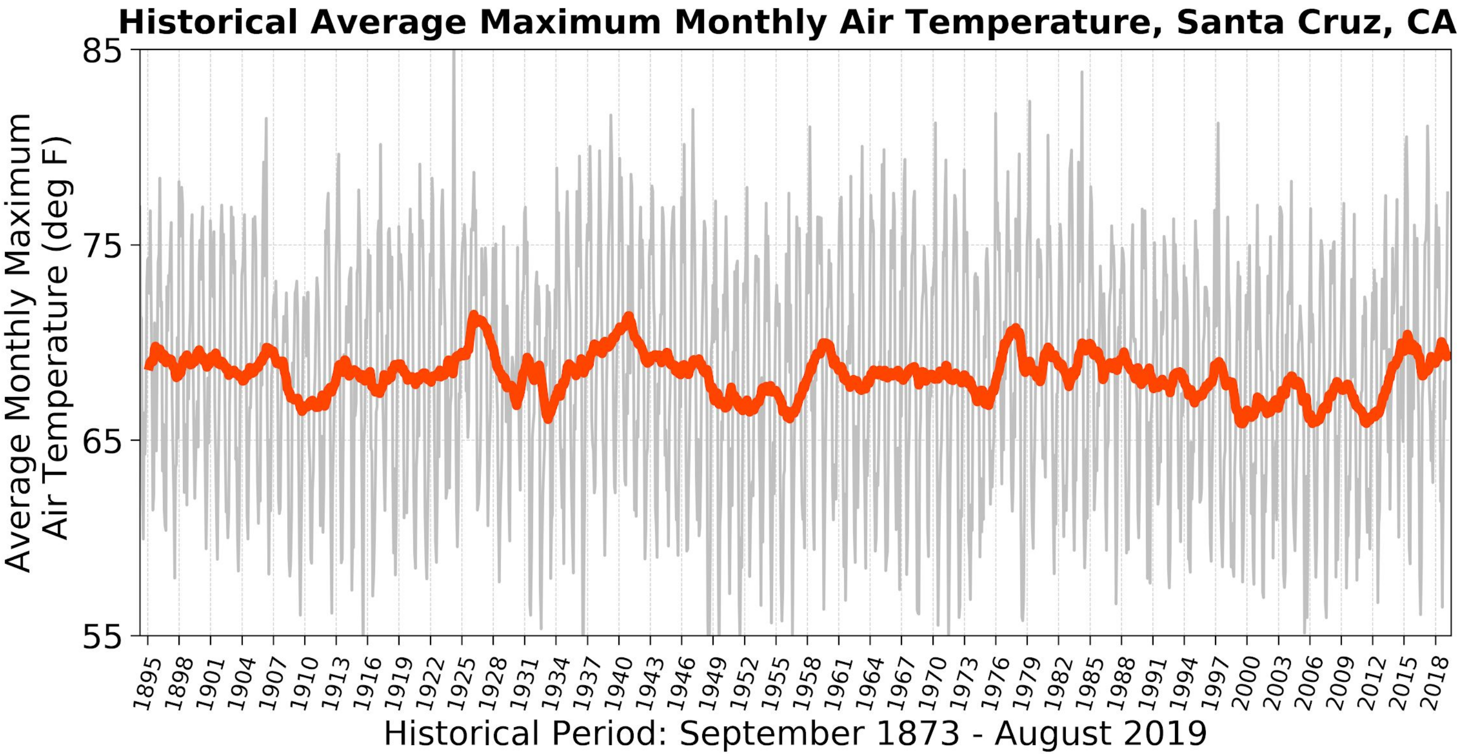
HISTORICAL CLIMATE
Avg. Air Temp

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



Balance Hydrologics, Inc.

HISTORICAL CLIMATE
Max Air Temp



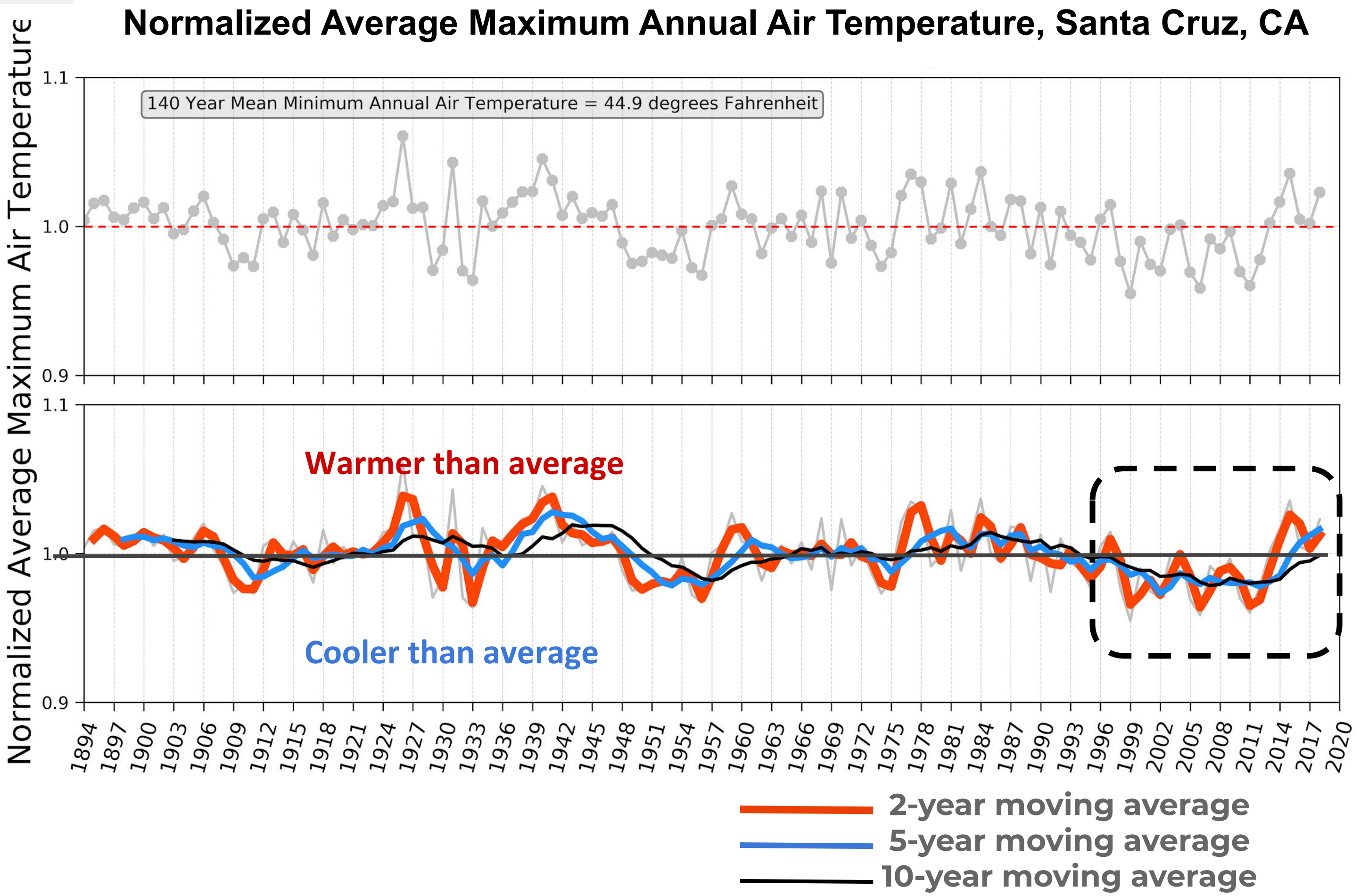
What have we observed in the past 100 years+ in terms of the S.C. climate?

24-month moving average

Balance Hydrologics, Inc.

HISTORICAL CLIMATE
Max Air Temp

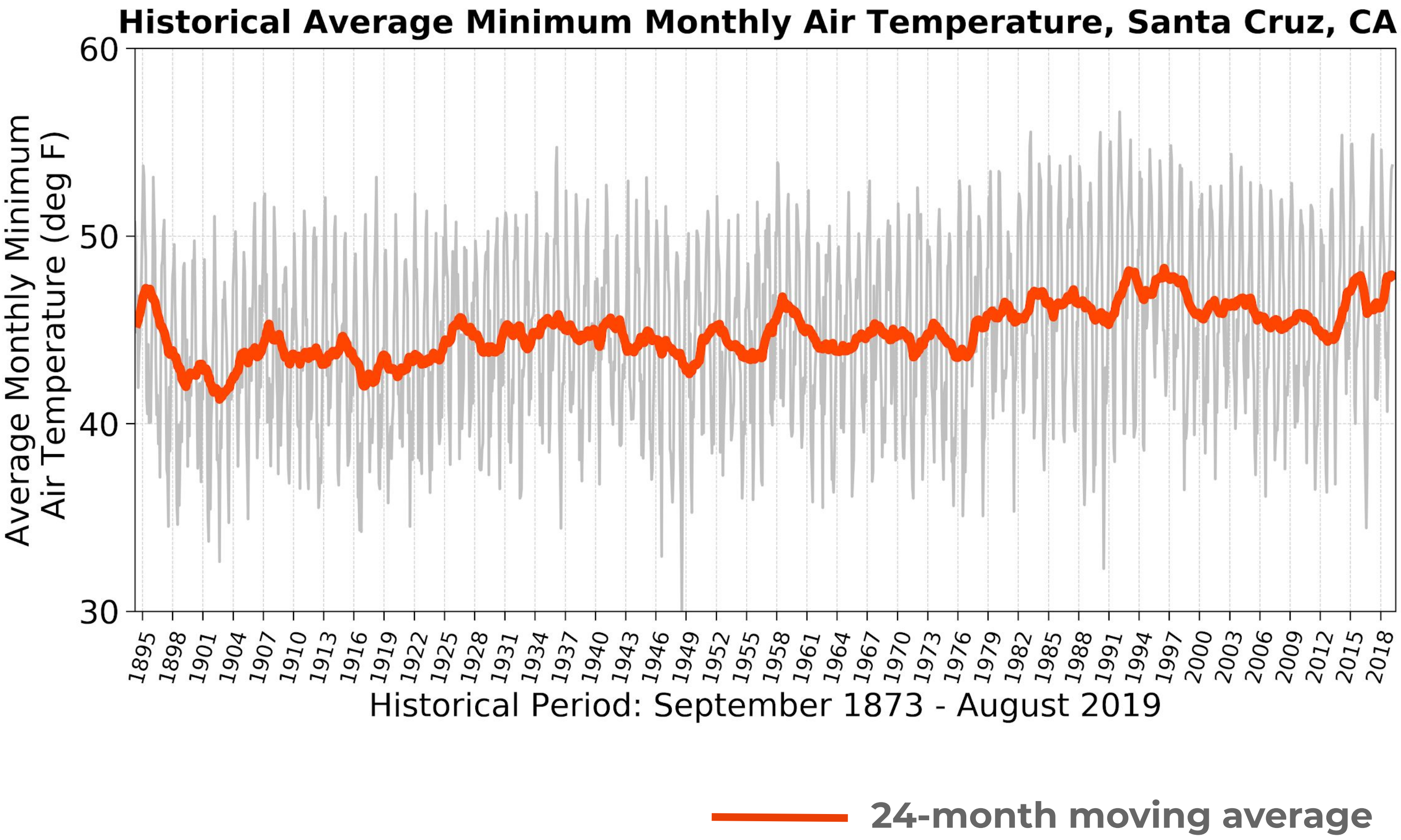
What have we observed in the past 100 years+ in terms of the S.C. climate?



Balance Hydrologics, Inc.

HISTORICAL CLIMATE
Min Air Temp

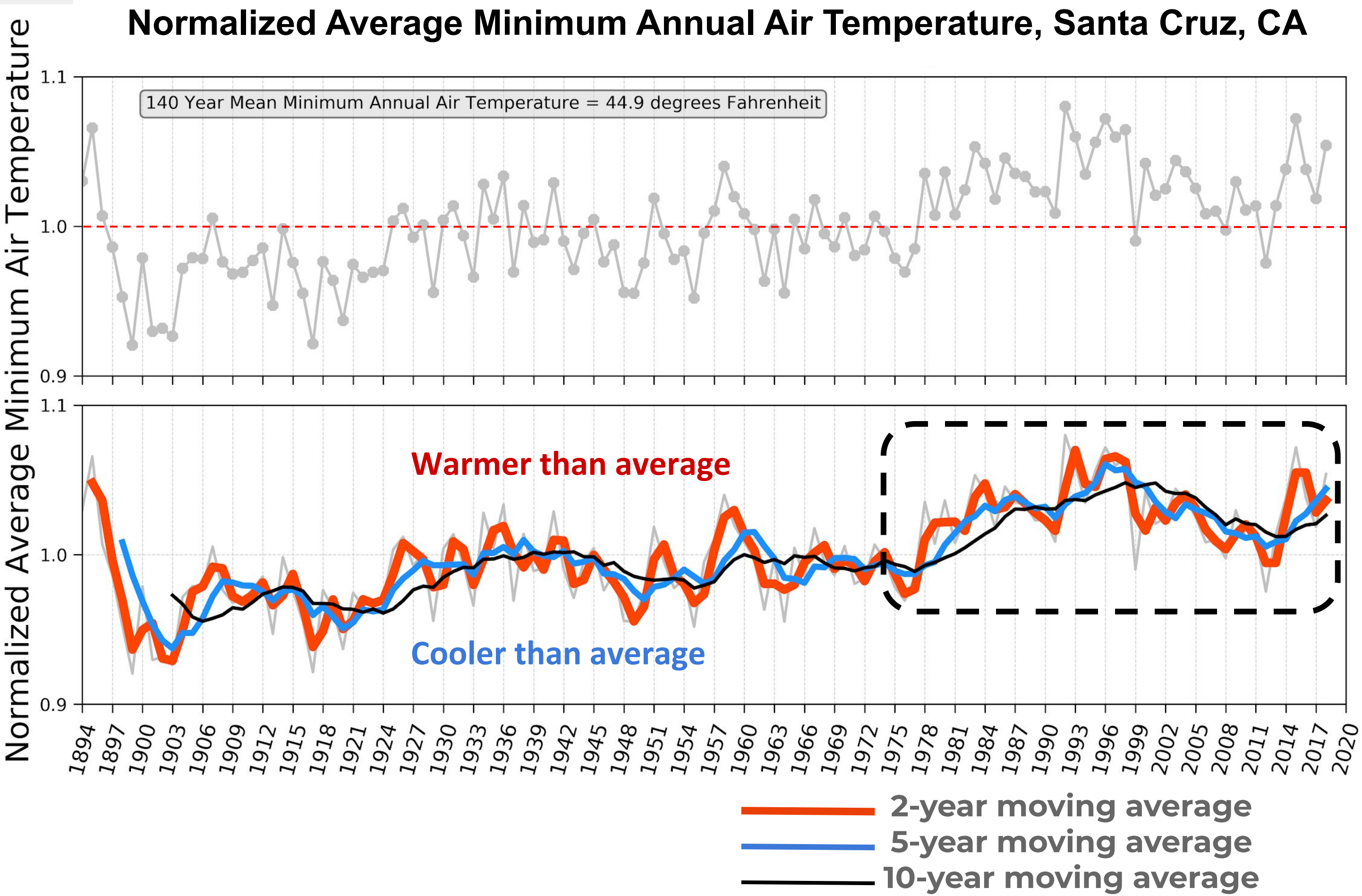
What have we observed in the past 100 years+ in terms of the S.C. climate?



Balance Hydrologics, Inc.

HISTORICAL CLIMATE
Min Air Temp

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



Balance Hydrologics, Inc.

What We Learn from the Historical Climate at Santa Cruz

- **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

Balance Hydrologics, Inc.

What We Learn from the Historical Climate at Santa Cruz

- 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

Balance Hydrologics, Inc.

What We Learn from the Historical Climate at Santa Cruz

- 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

Balance Hydrologics, Inc.

What We Learn from the Historical Climate at Santa Cruz

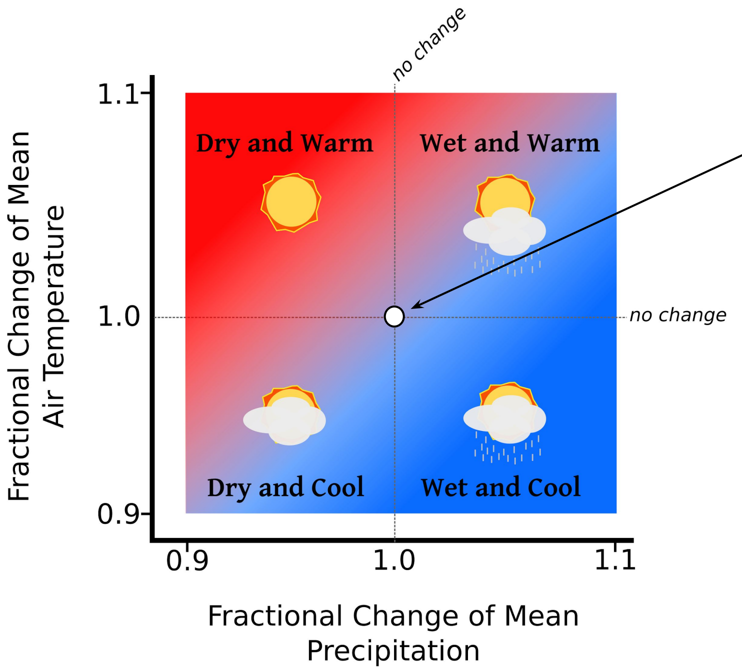
- Regularity of multi-year swings of precipitation has increased - WY12-15 drought is historically severe
- Mean air temperatures of recent 35 years historically warm
- Maximum air temperature shows an increasing trend over the past 7 yrs.
- **Minimum air temperatures of recent 35 years historically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

Balance Hydrologics, Inc.

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

Balance Hydrologics, Inc.

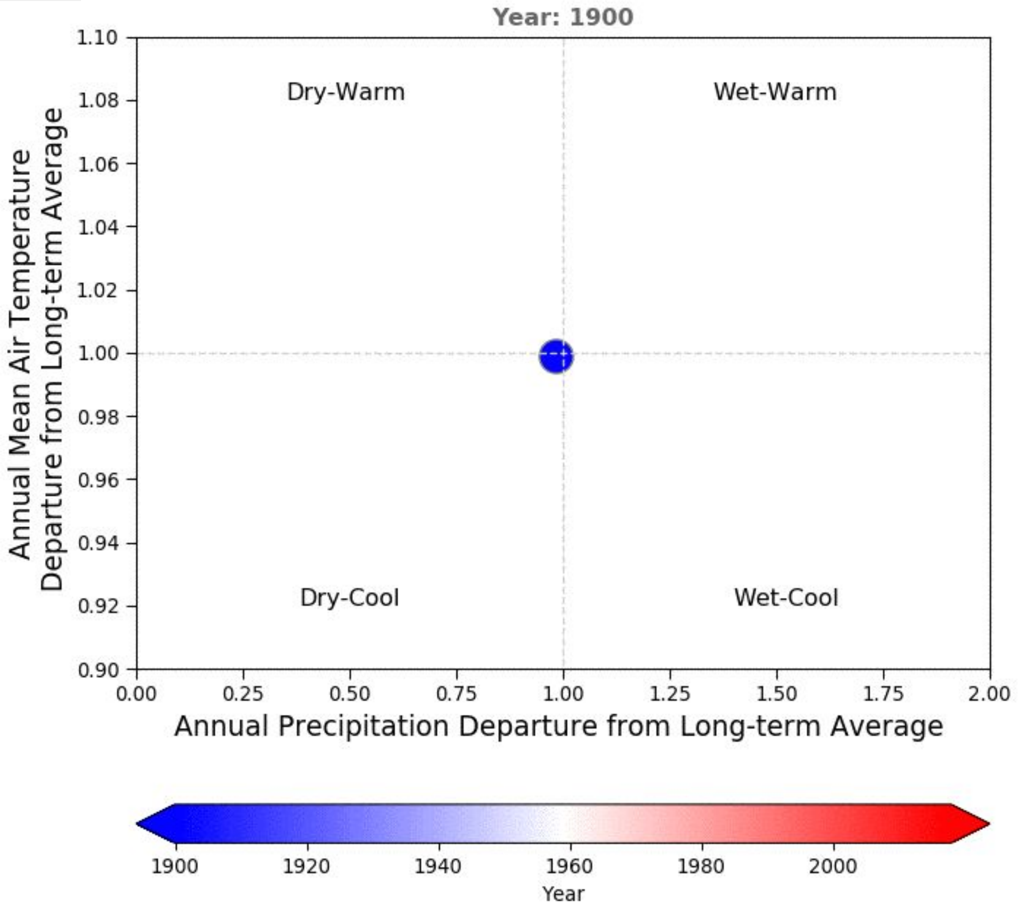
What We Learn from the Historical Climate at Santa Cruz



Historical average conditions

Balance Hydrologics, Inc.

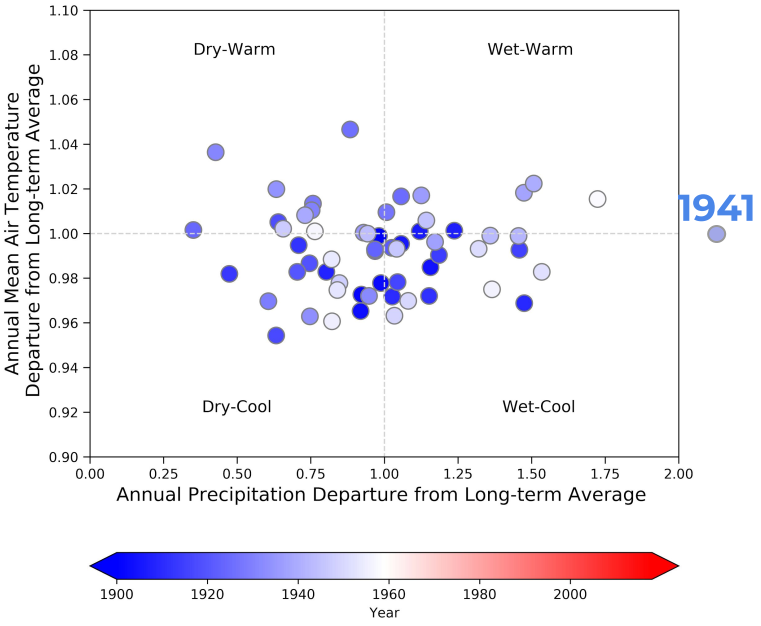
HISTORICAL CLIMATE
Deeper Look



Balance Hydrologics, Inc.

HISTORICAL CLIMATE
Deeper Look

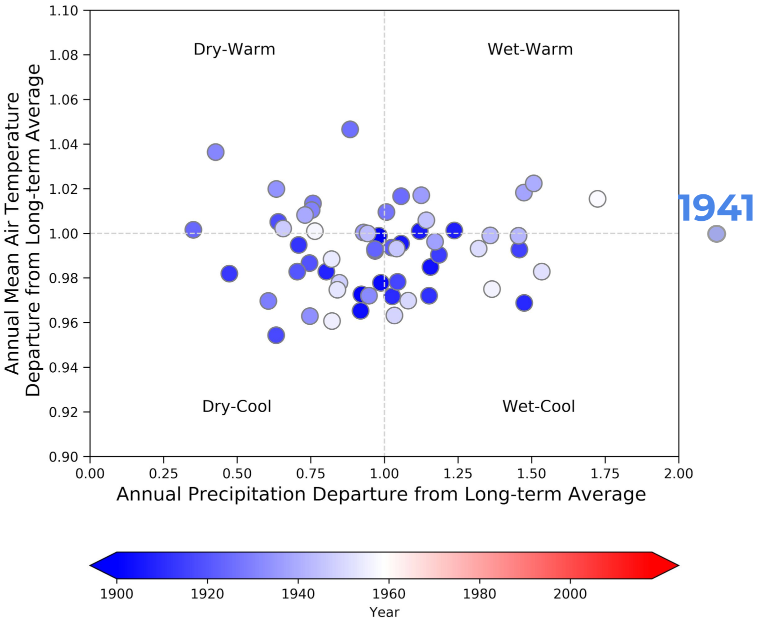
1900-1958



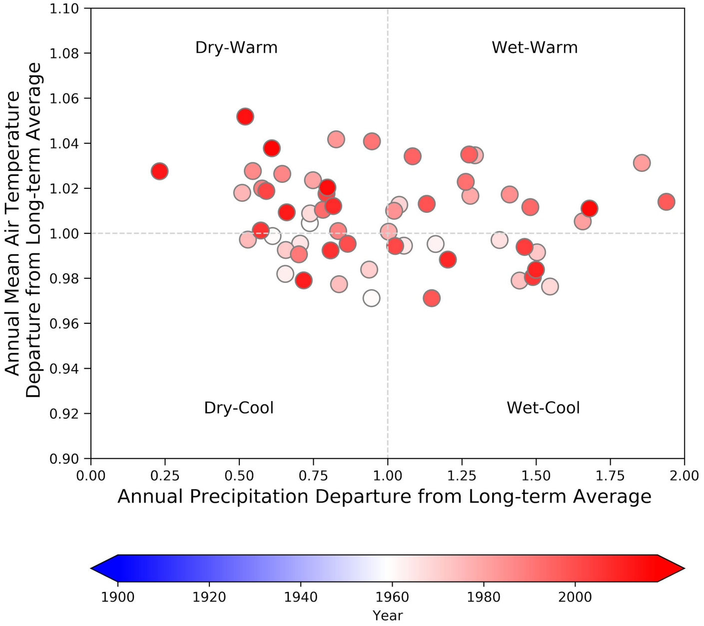
Balance Hydrologics, Inc.

HISTORICAL CLIMATE
Deeper Look

1900-1958



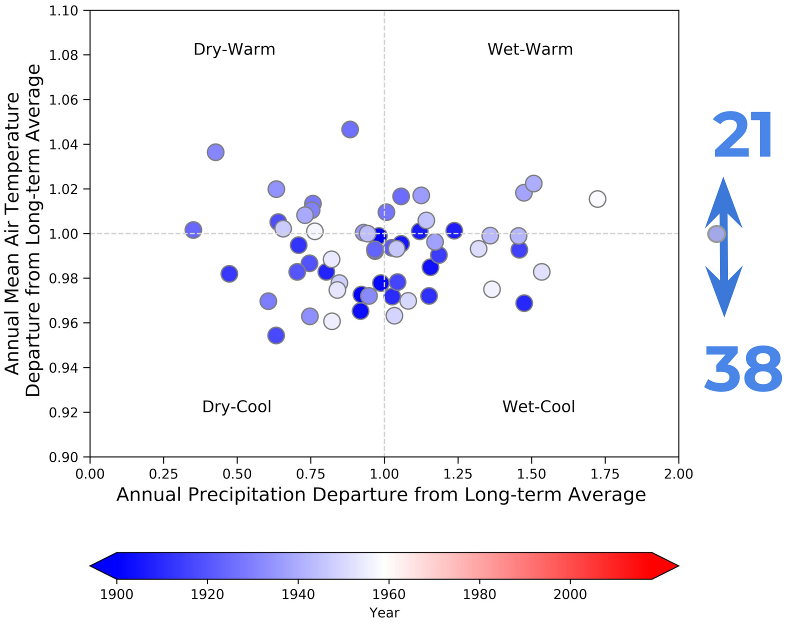
1959-2018



Balance Hydrologics, Inc.

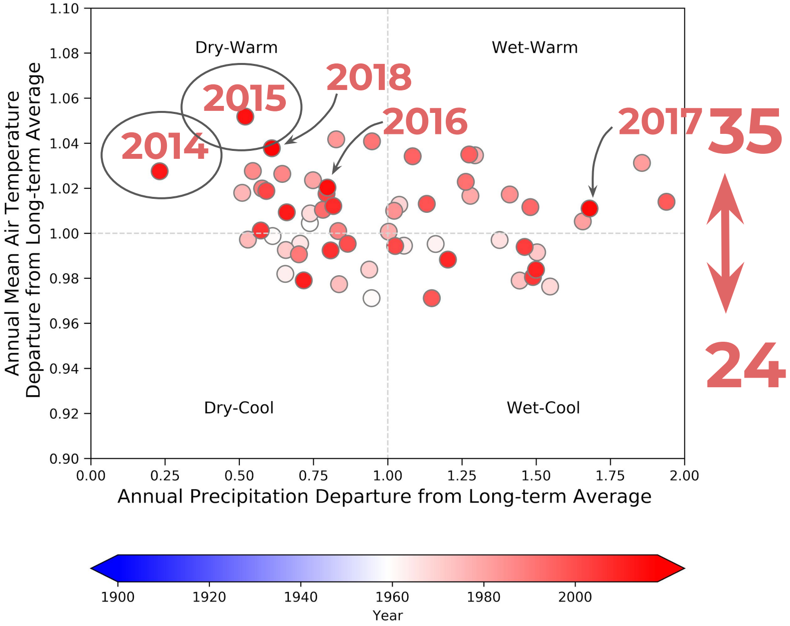
HISTORICAL CLIMATE
Deeper Look

1900-1958



Cooler

1959-2018

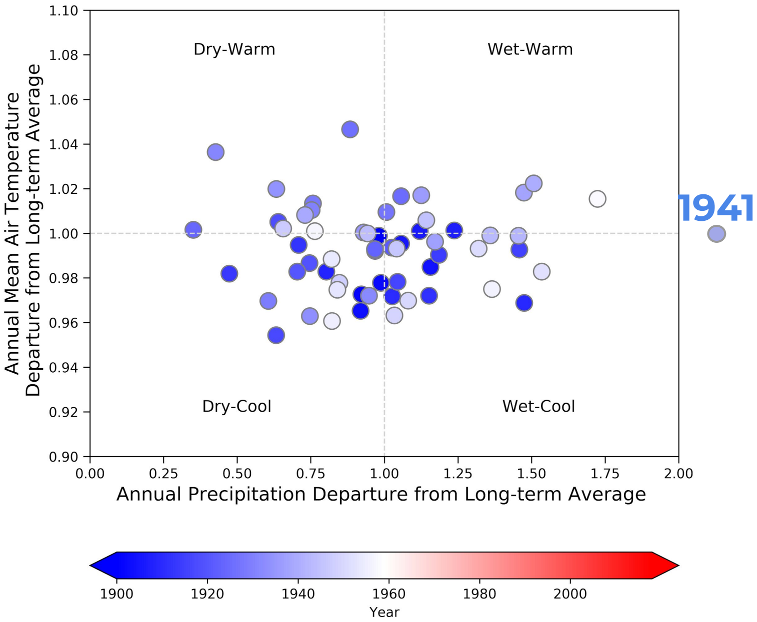


Warmer

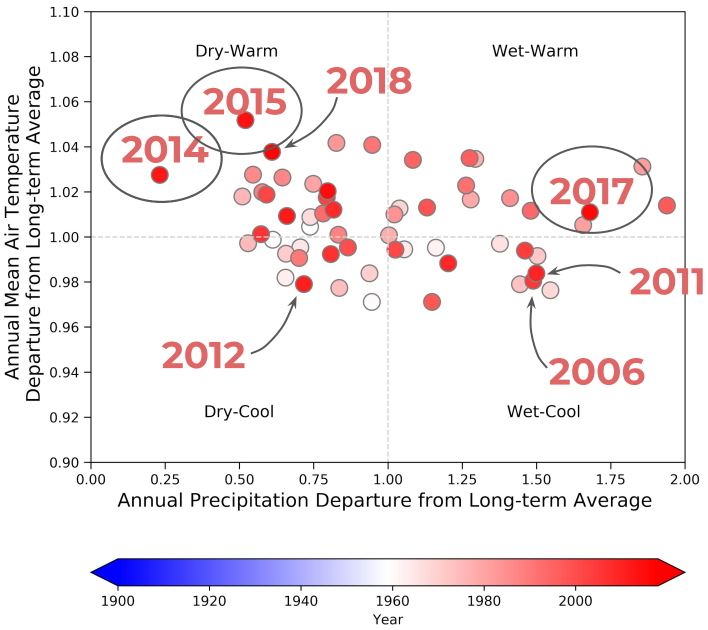
Balance Hydrologics, Inc.

HISTORICAL CLIMATE
Deeper Look

1900-1958



1959-2018



Less Range in Precip

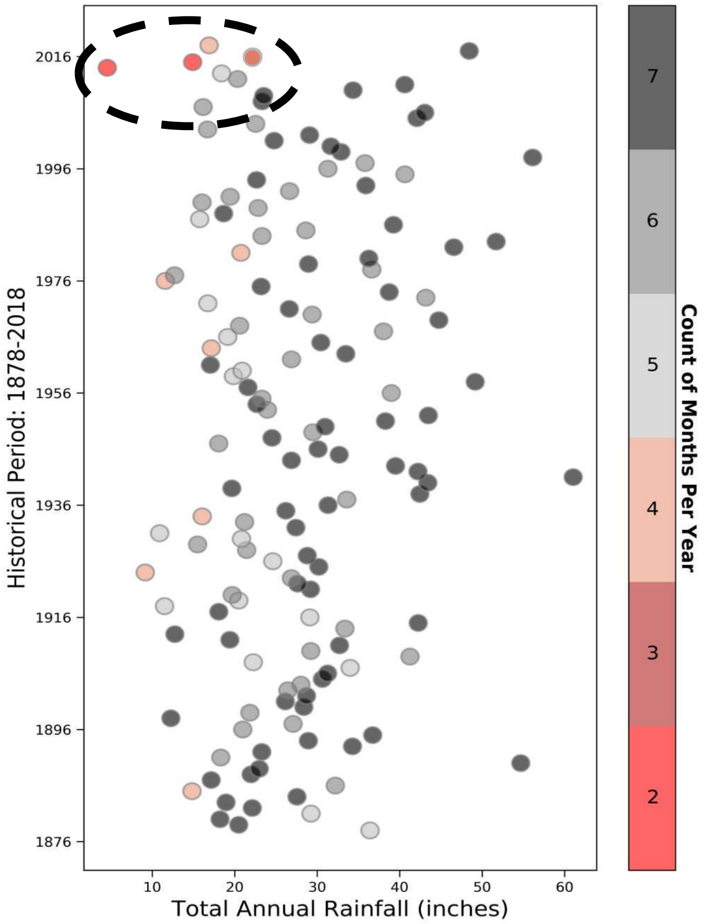
More Frequent Flips in Precip

Balance Hydrologics, Inc.

Runoff producing rainfall recorded in fewer months of the year

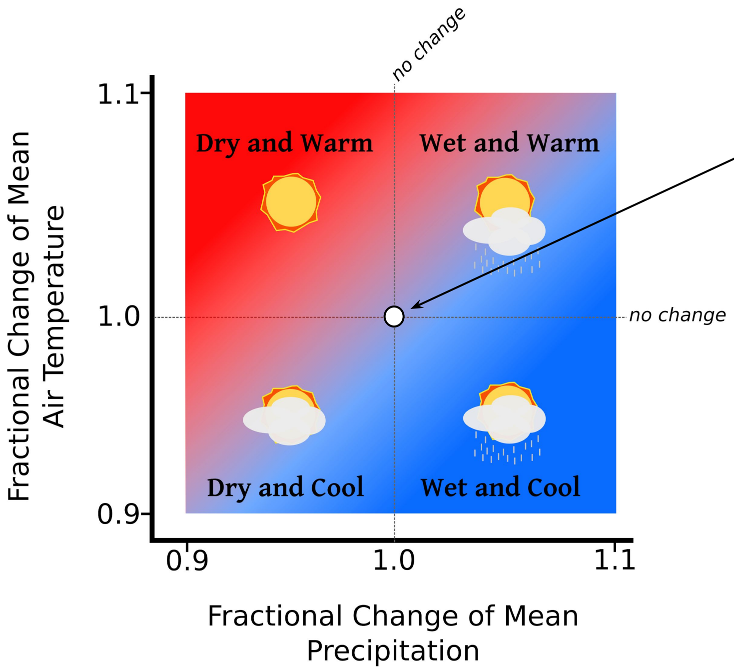
[and we know those months are also warmer than average]

More than 0.5-inches of Rainfall



Balance Hydrologics, Inc.

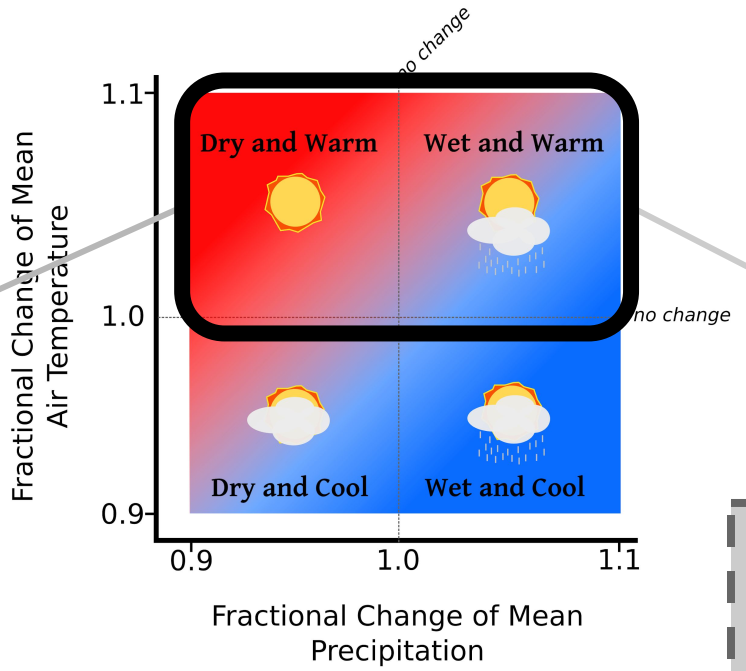
How the Historical Climate Links to Our Climate Change Work



Historical average conditions

How the Historical Climate Links to Our Climate Change Work

Greater rainfall variability, more severe droughts



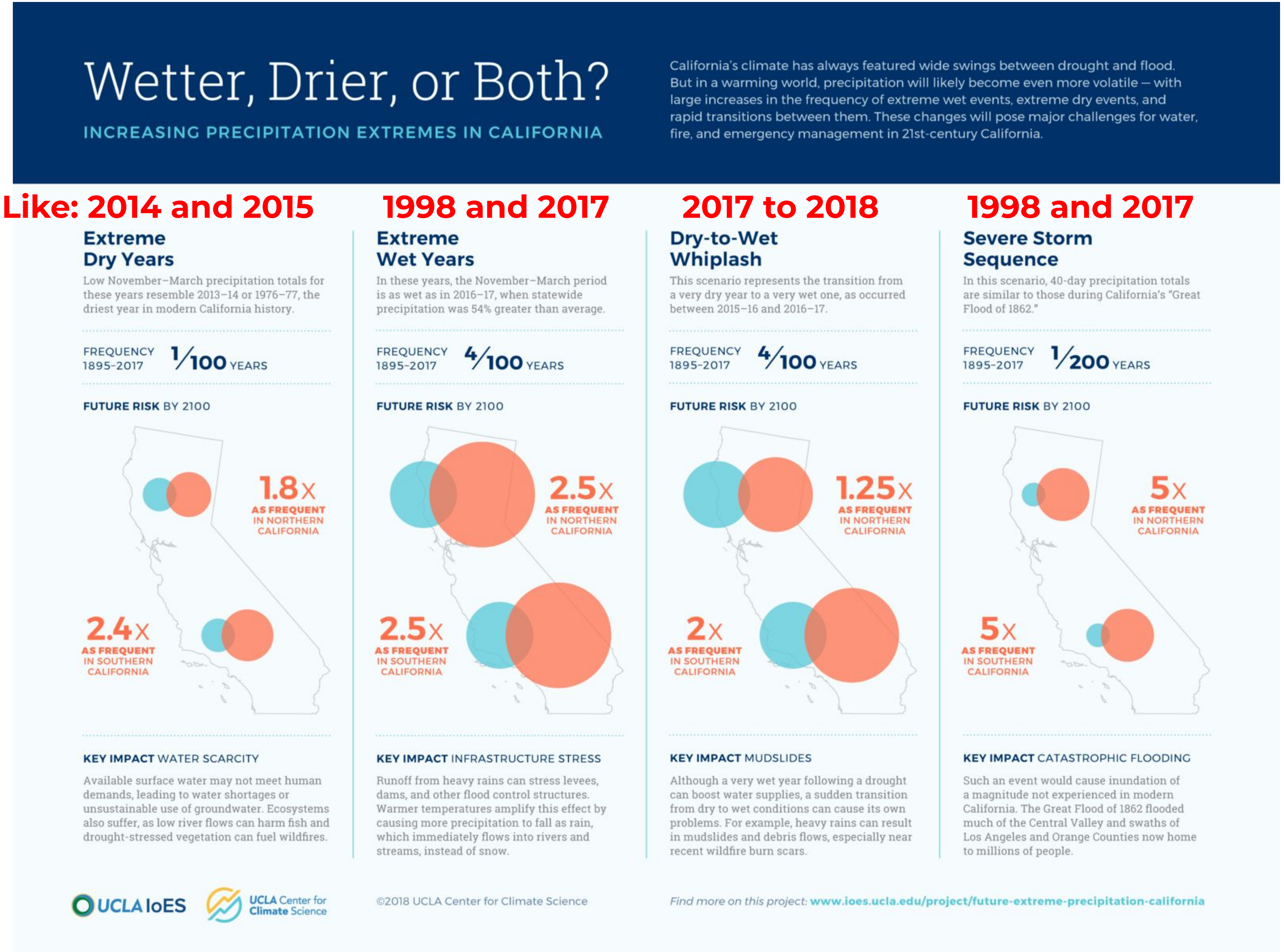
Warmer

Fewer Months of Rainfall/Yr.

Balance Hydrologics, Inc.

PROJECTED CLIMATE

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



Balance Hydrologics, Inc.

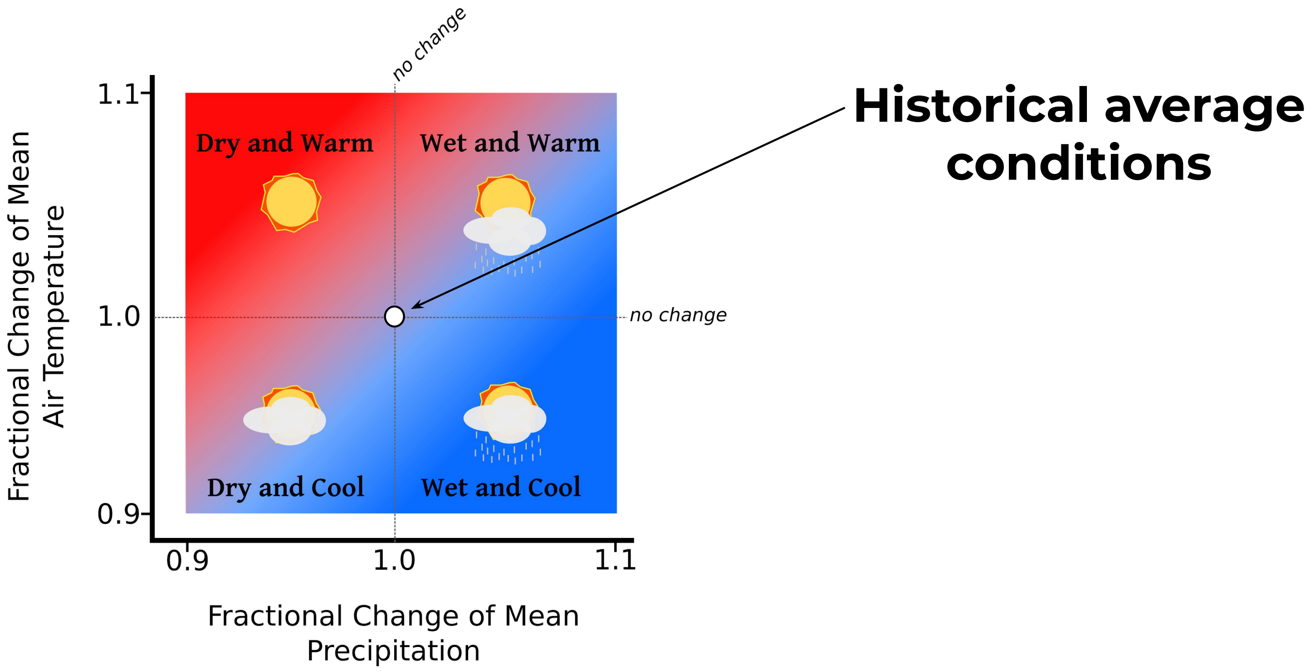
Source: https://www.ioes.ucla.edu/article/study-forecasts-a-severe-climate-future-for-california/

Overview of Modeling Plausible Future Streamflows

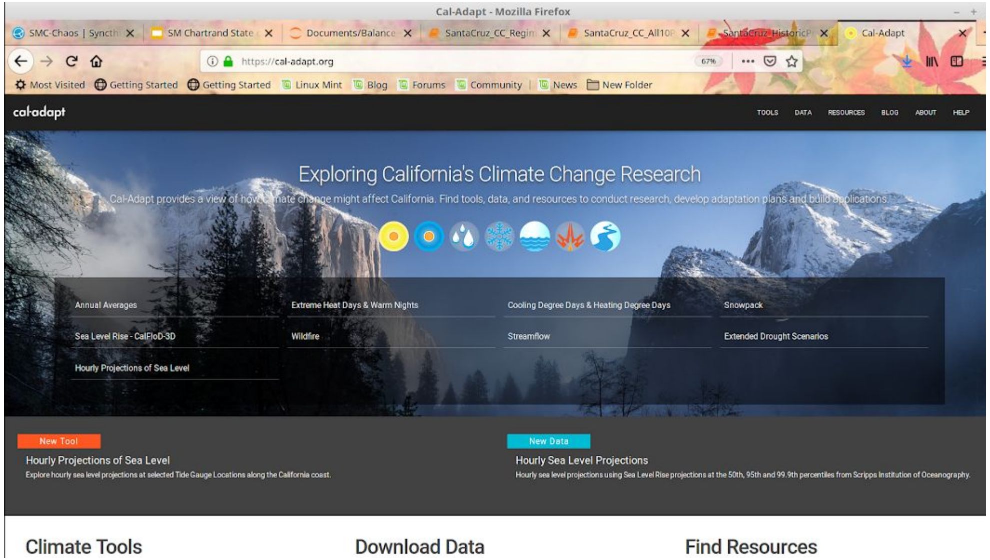
1. General Strategy
2. Limitations and Assumptions
3. **Projected Climate Conditions Evaluated with the Hydrology Model**

Balance Hydrologics, Inc.

Use a Simple Framework to Understand Projections of Climate



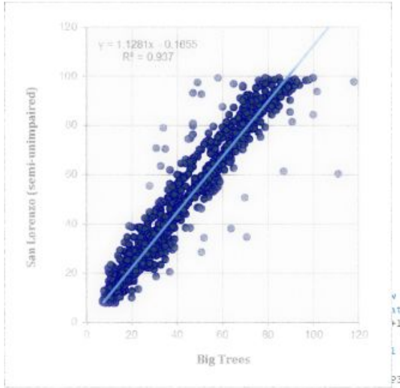
Use a Public-domain CC Data to Develop Projections of Streamflow



https://cal-adapt.org

Balance Hydrologics, Inc.

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)

l i-1 WY type is dry or drier and cell i is

P3(i-1,8) <= 2 && MJAHCP3(i,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 = 13:-1:1;
z = length(less);
flow = MJAHCP3(i-less,4);
[flowgreater] = find(flow > MJAMig(1,1));
numberofvalues = length(flowgreater);
last = max(flowgreater);

if numberofvalues >= 2

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

Balance Hydrologics, Inc.

Use an Empirical-based Model to Develop Projections of Streamflow

Specify Water Balance Model

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

Q: Streamflow

P: Precipitation

ET: Evapotranspiration (Air Temp)

R: Recharge*

B: Baseflow*

Balance Hydrologics, Inc.

Use an Empirical-based Model to Develop Projections of Streamflow

1950 - 2000
Develop Calibration Model

Measured Streamflow at USGS Big Trees

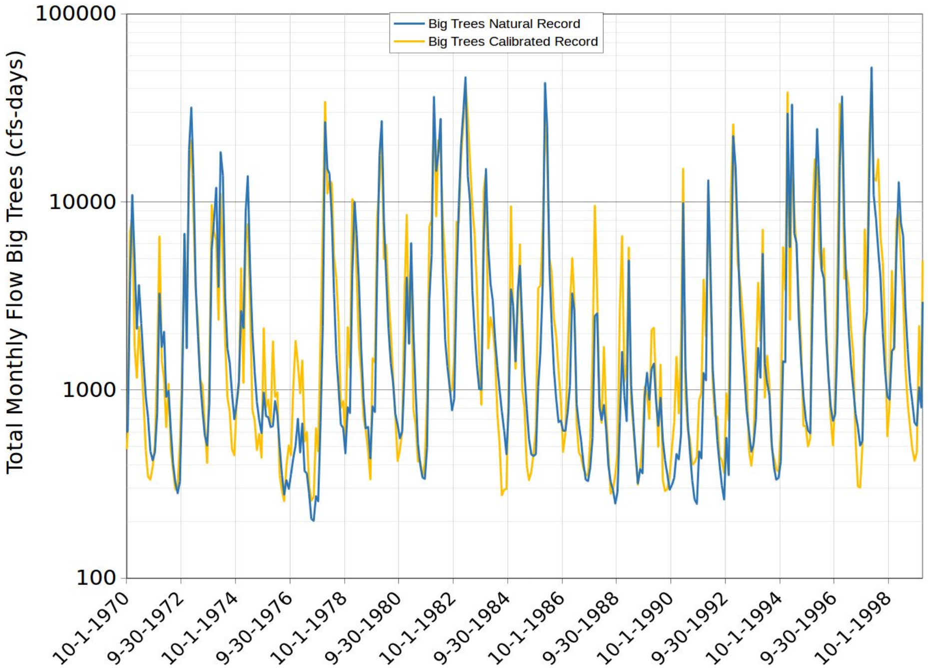
minimize error*

Projected Streamflow at USGS Big Trees

Water Balance Model (Precip, Air Temp)

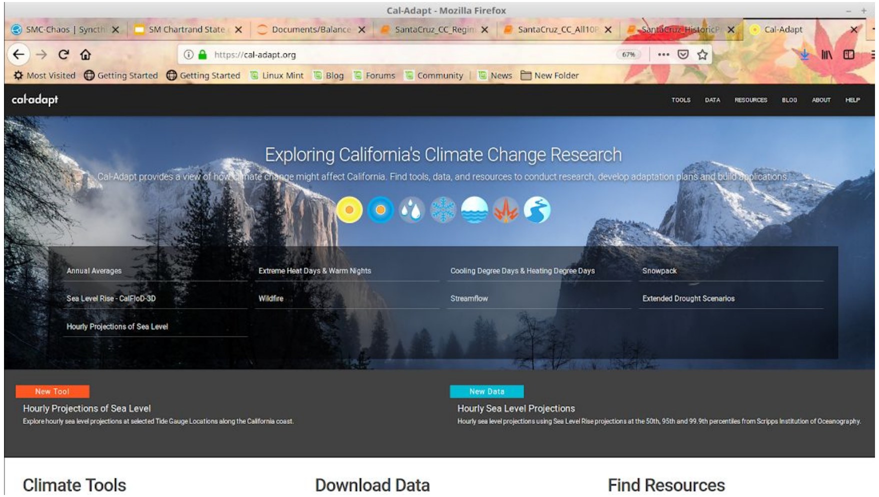
Balance Hydrologics, Inc.

Use an Empirical-based Model to Develop Projections of Streamflow



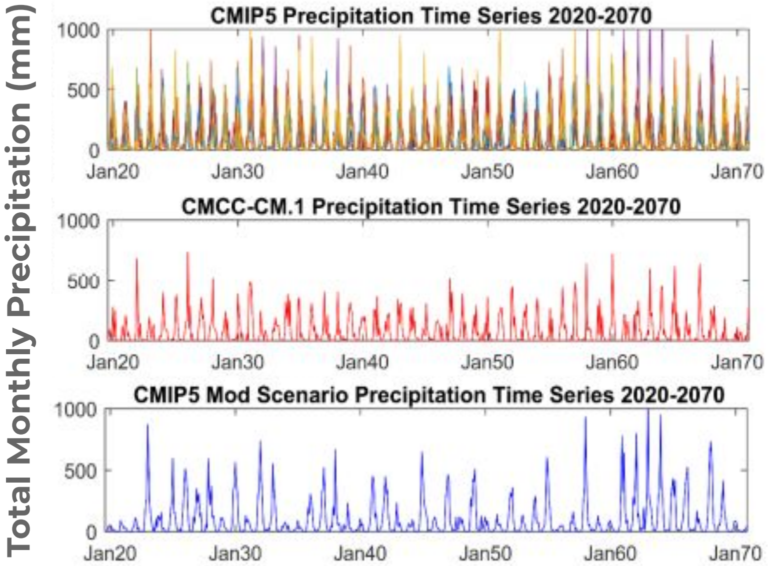
Use an Empirical-based Model to Develop Projections of Streamflow

2020-2070
Acquire CC Data - CalAdapt



Use an Empirical-based Model to Develop Projections of Streamflow

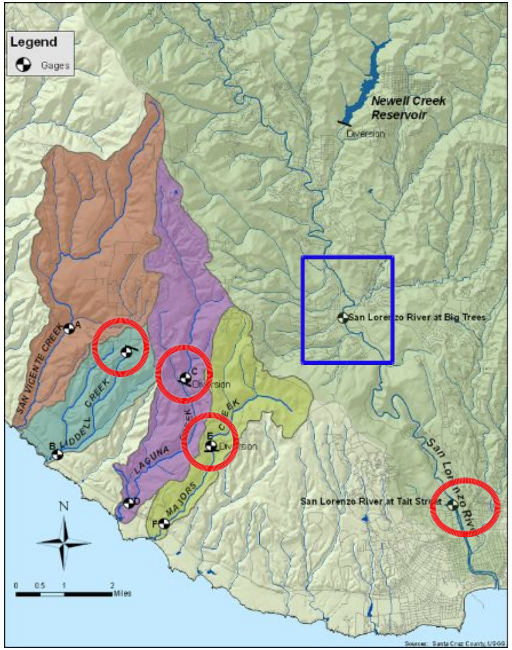
Execute Water Balance Model



Balance Hydrologics, Inc.

Use an Empirical-based Model to Develop Projections of Streamflow

Execute HCP Hydrology Model



Location of Climate Change Projections

Locations of Production

Use an Empirical-based Model to Develop Projections of Streamflow

Execute HCP Hydrology Model

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.

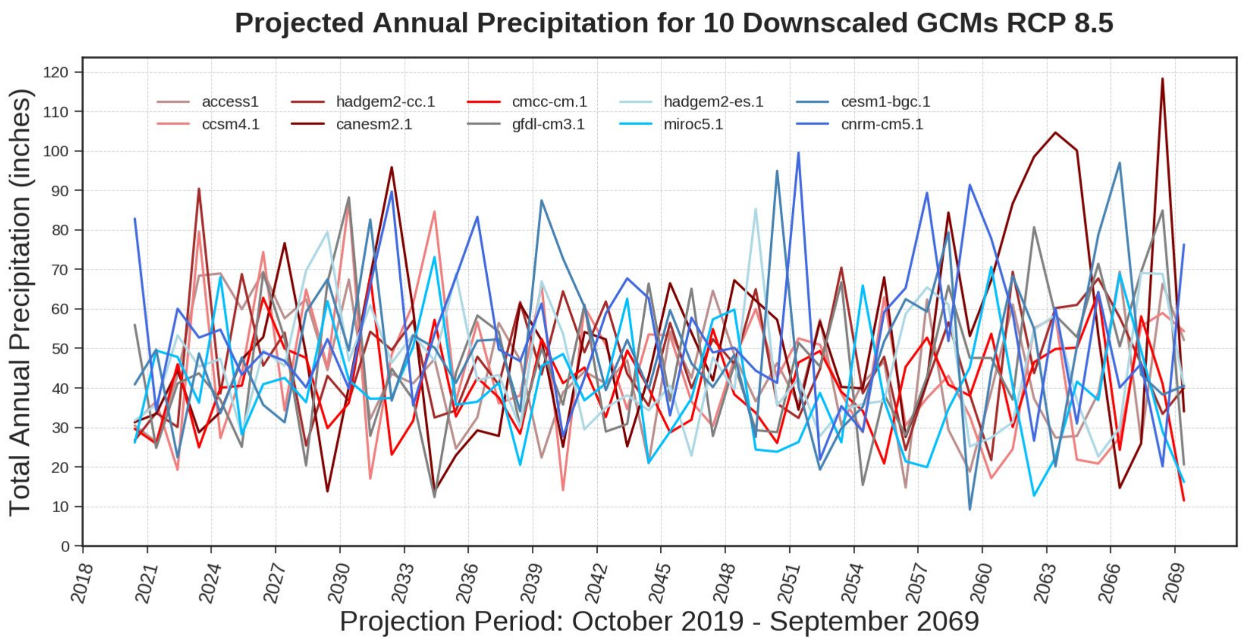
2. Water balance model limited to "average" flow conditions at Big Trees, i.e. wet and dry flows could be more severe than projected.

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**

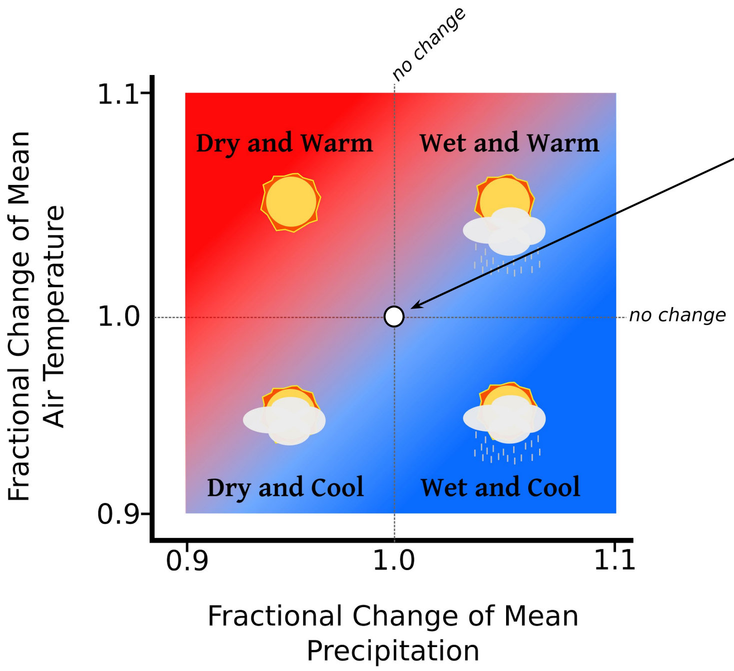
Balance Hydrologics, Inc.

Use a Simple Framework to Understand Projections of Climate



Balance Hydrologics, Inc.

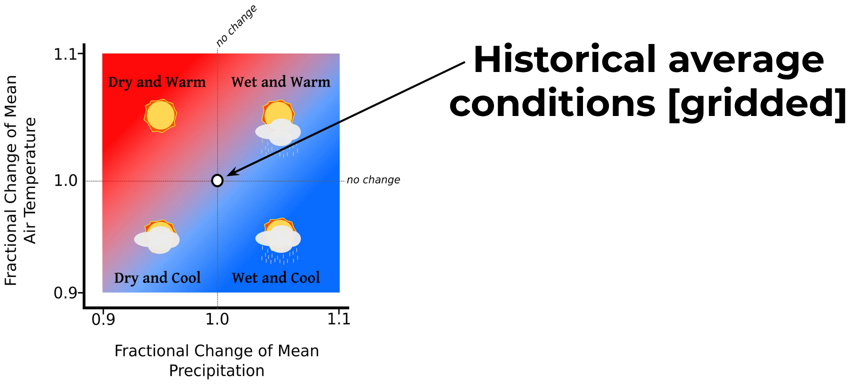
Use a Simple Framework to Understand Projections of Climate

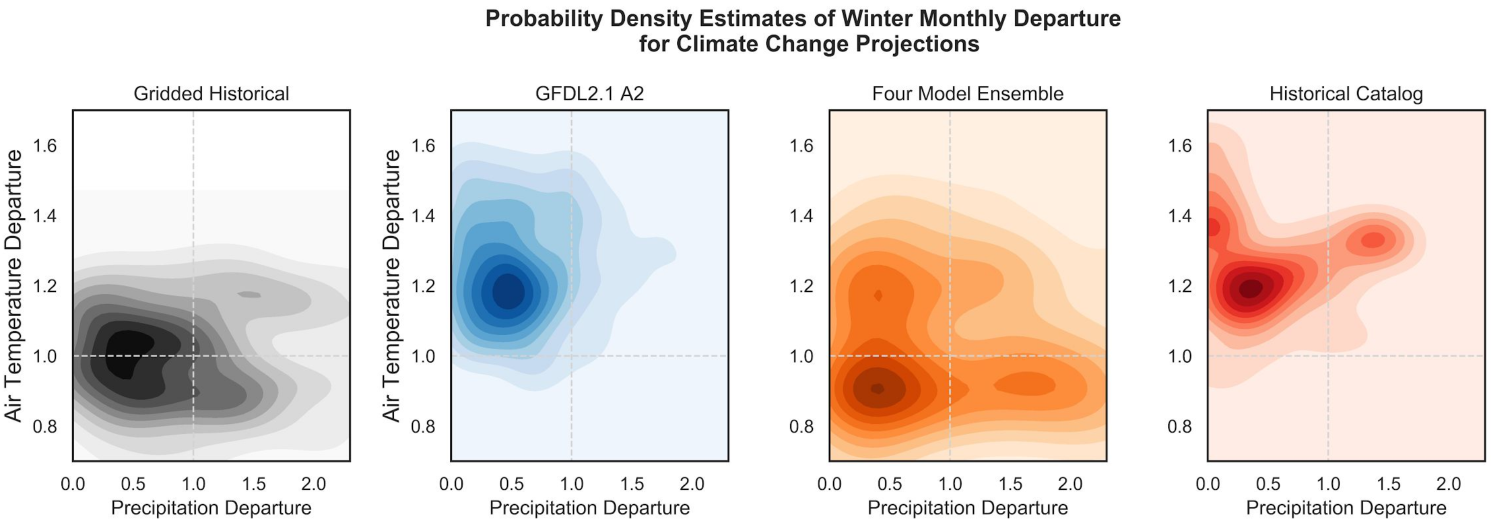


Historical average conditions

Balance Hydrologics, Inc.

PROJECTED CLIMATE
Projected Conditions



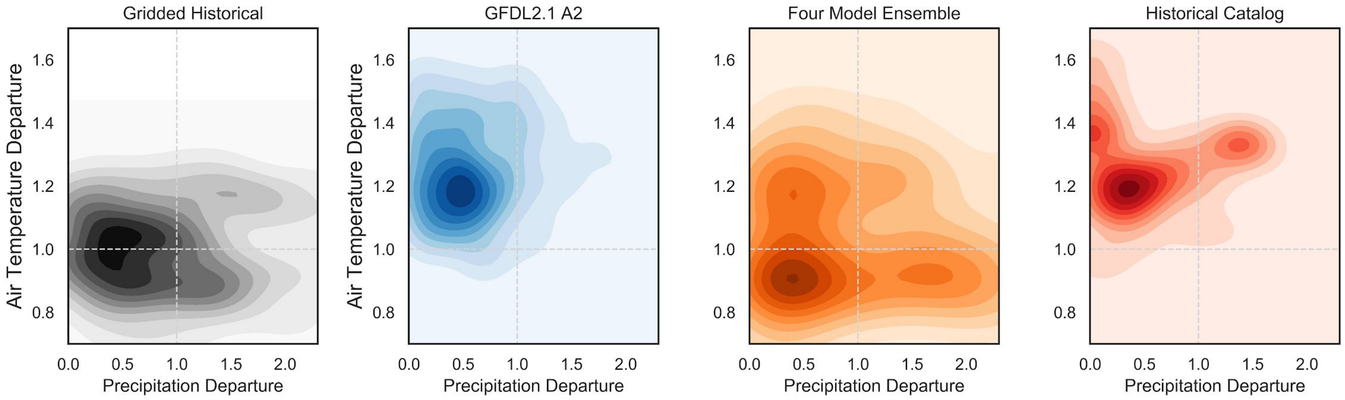


Balance Hydrologics, Inc.

Time Period: 2020-2070

PROJECTED CLIMATE
Projected Conditions

Probability Density Estimates of Winter Monthly Departure for Climate Change Projections



Water balance model

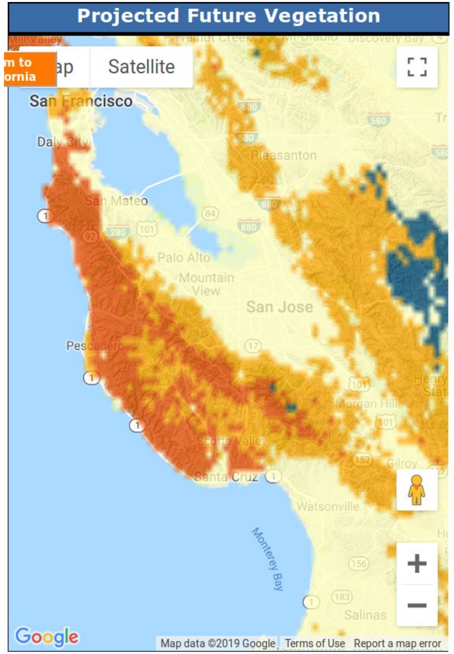
HCP hydrology model

Santa Margarita Basin Groundwater Model

Santa Margarita Basin Groundwater Water Supply Conditions

Balance Hydrologics, Inc.

What We Learn from Climate Projections at Santa Cruz



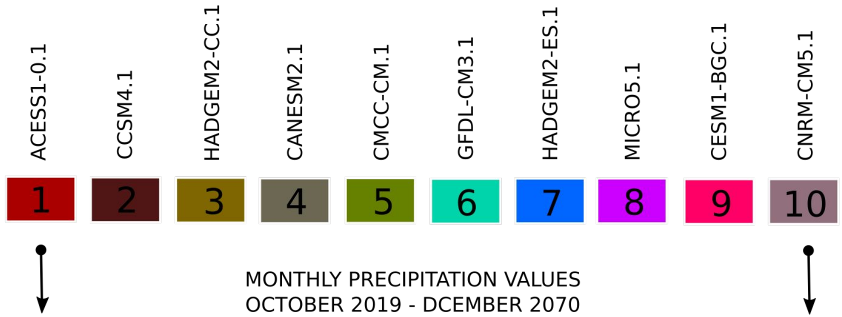
Point Blue, Conservation Science

- 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?

Balance Hydrologics, Inc.

QUESTIONS?

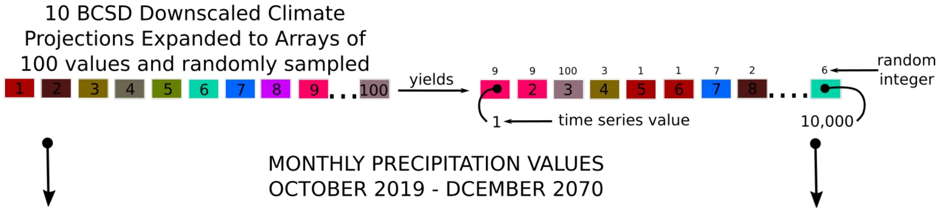
10 BCSD Downscaled Climate Projections



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.



Balance Hydrologics, Inc.