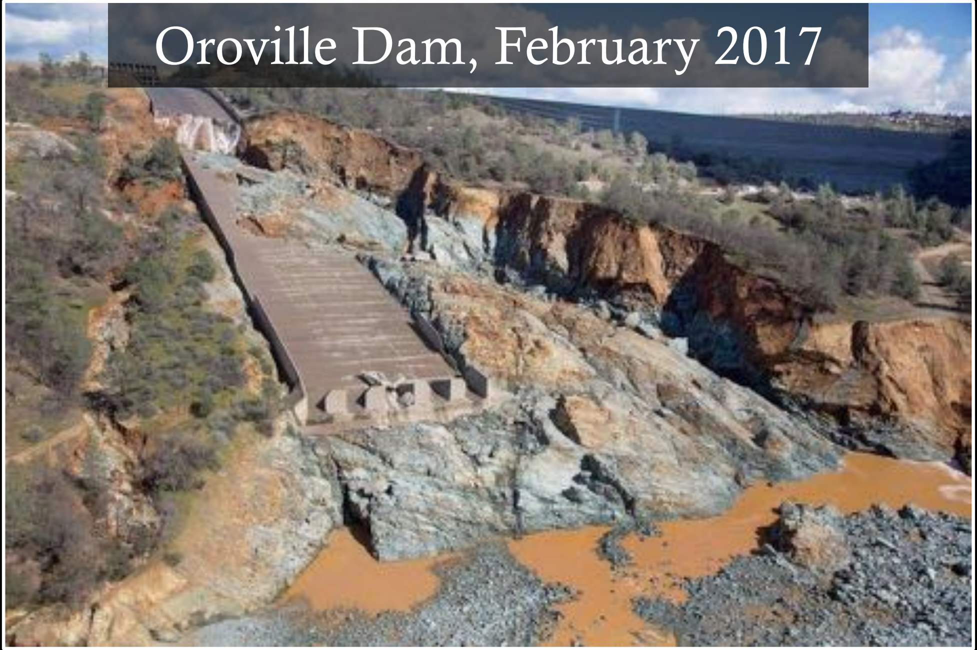
Warmer and wilder: Increasing water resource variability in a changing California

Oroville Dam, February 2017



Camp Fire, November 2018

Daniel Swain

UCLA, NCAR, The Nature Conservancy

California Water Efficiency Partnership Annual Conference

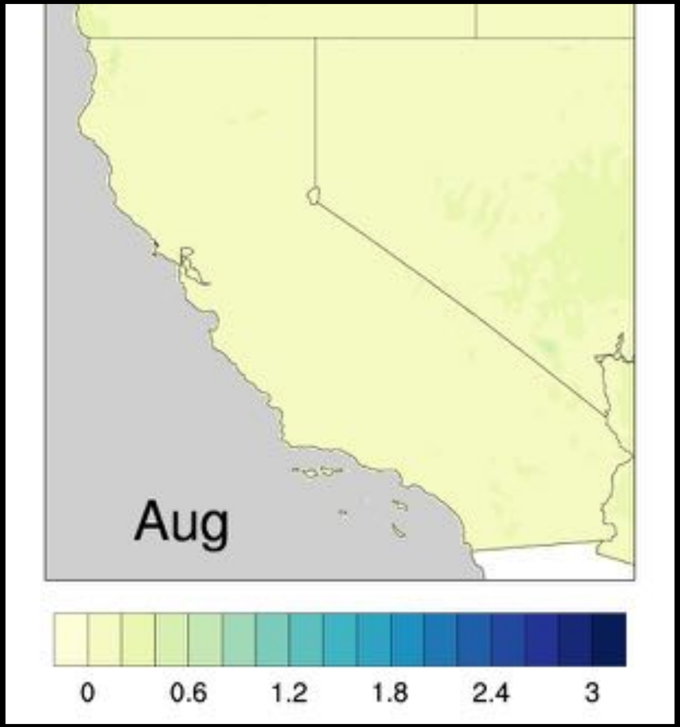
June 2021

Daniel Swain
dlswain@ucla.edu
www.weatherwest.com
@Weather_West

UCLA IoES
NCAR
The Nature Conservancy

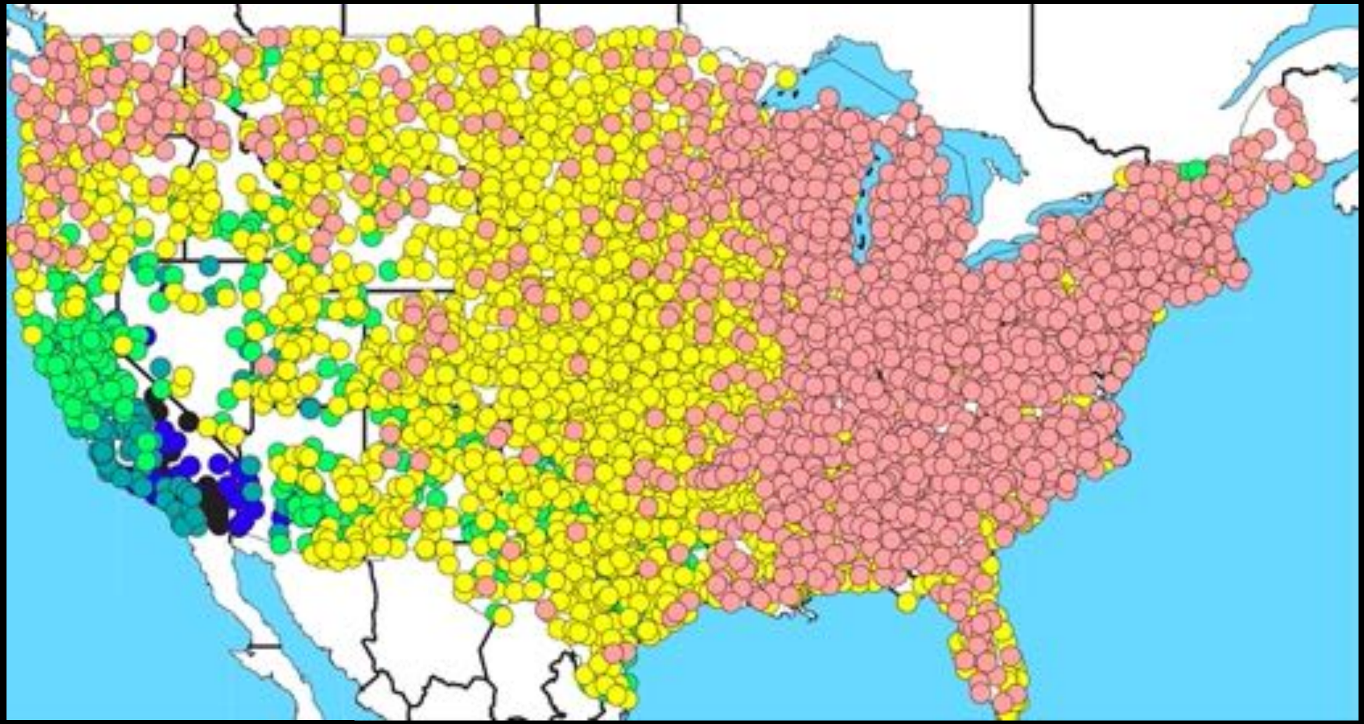
Primer: California's unusual climate context

Monthly precipitation



Swain 2016

Coefficient of variation in annual precipitation



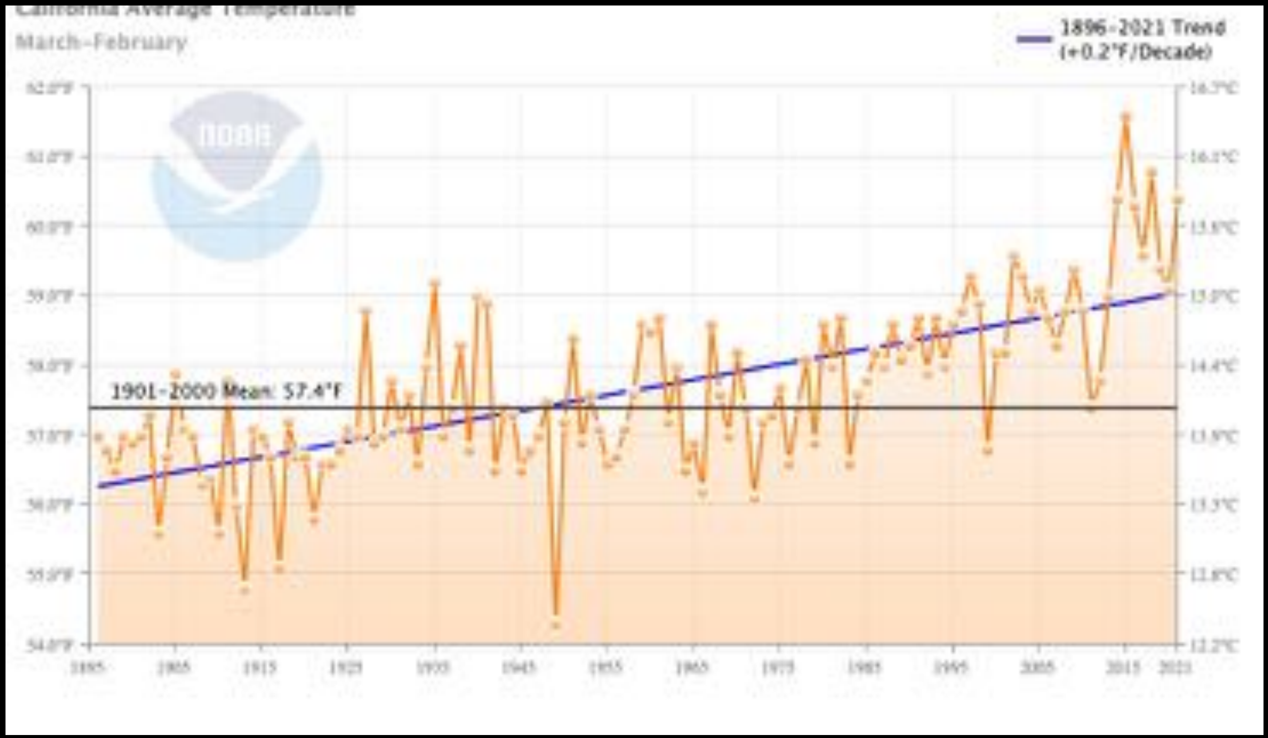
Dettinger 2011

- California exists at margin of stable subtropics/active mid-latitudes
- Strong seasonal cycle of precipitation and latitudinal gradient
- Uniquely high year-to-year variation in precipitation; drought susceptibility

Daniel Swain
dlswain@ucla.edu
www.weatherwest.com
@Weather_West

California changes so far: warmer, less snow, more flammable

California annual average temperature (NOAA)



- California now significantly warmer than during early 20th century
- Mountain snowpack now detectably decreasing; snow lines increasing
- Large increase in wildfire size/severity

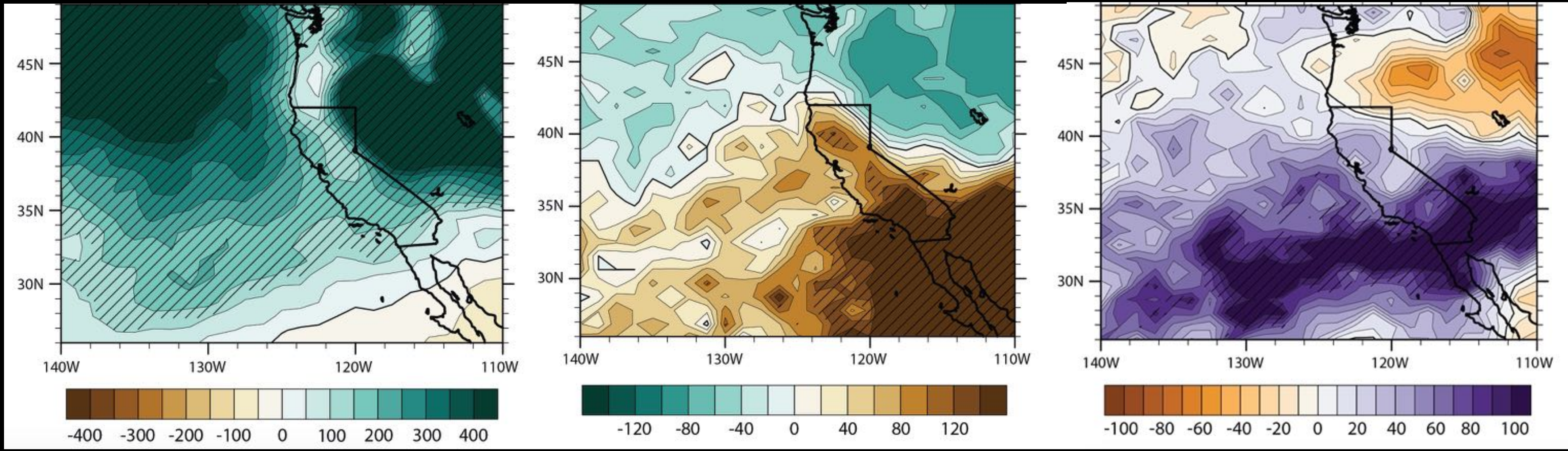
Daniel Swain
dlswain@ucla.edu
www.weatherwest.com
@Weather_West

A wetter *and* drier future?

Increase in very wet years

Increase in very dry years

Increase in "whiplash"



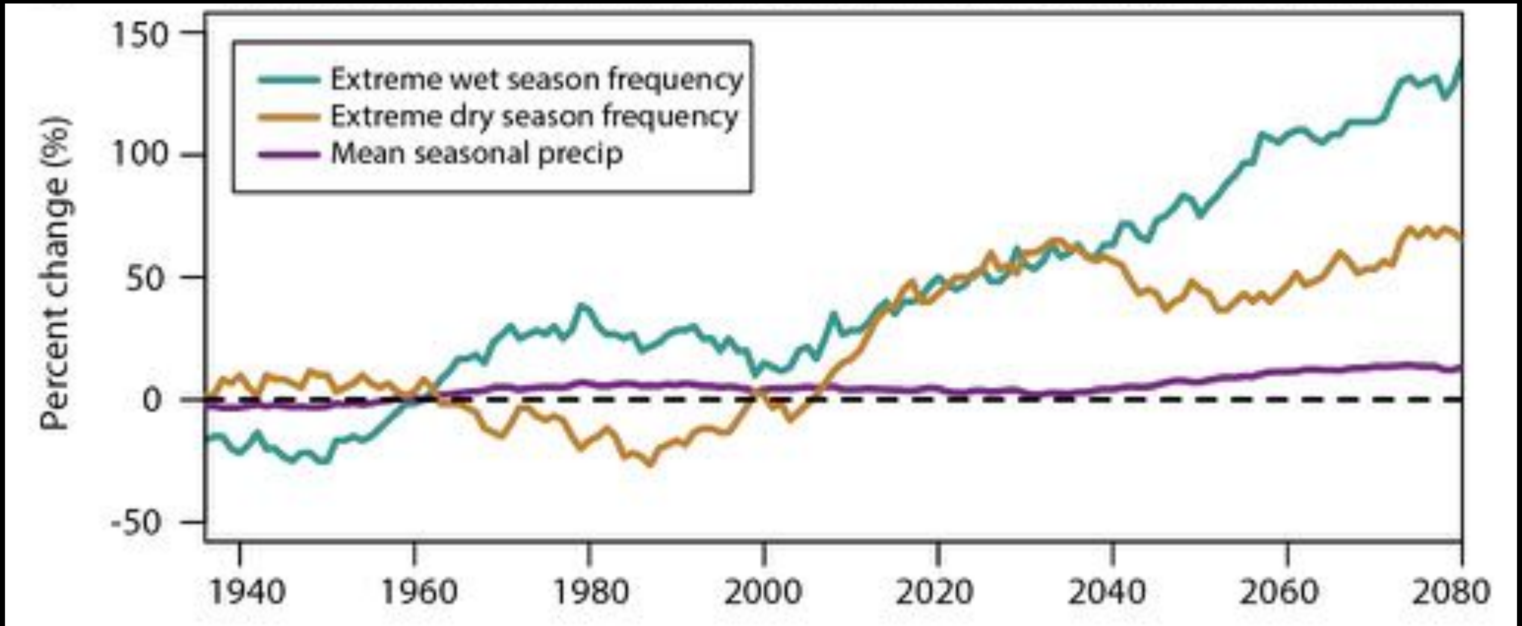
Swain et al. 2018

Large increase in both wet & dry extremes
despite little mean precip change!

Daniel Swain
dlswain@ucla.edu
www.weatherwest.com
@Weather_West

Increasing California precipitation extremes

Large increase in "precipitation whiplash"

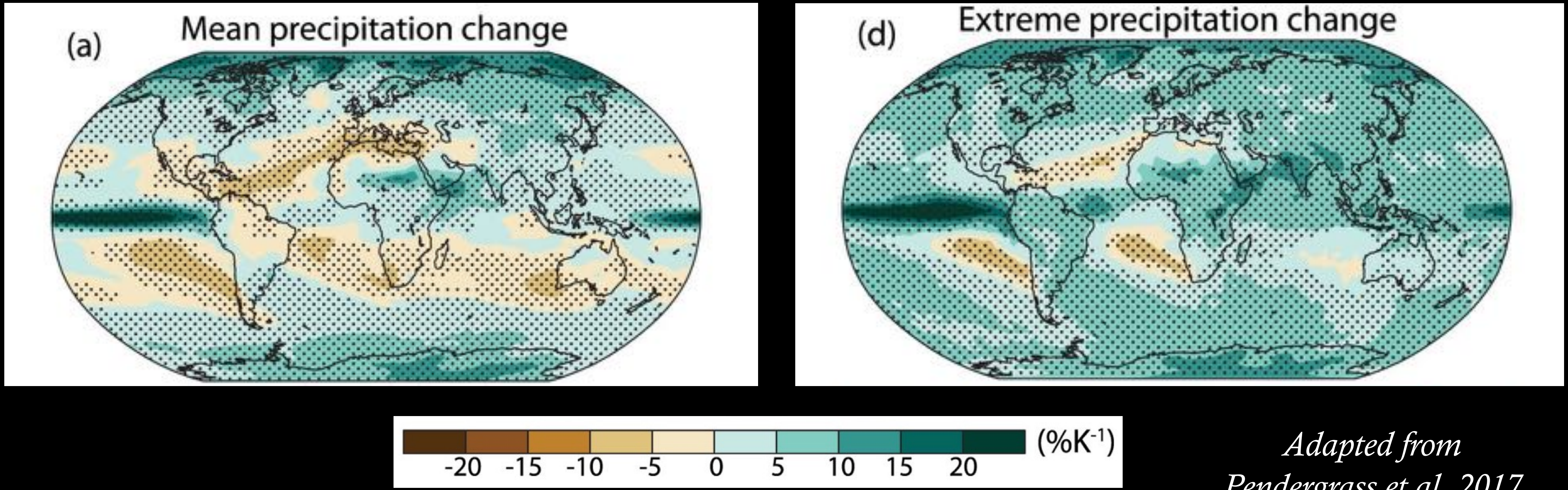


Change in frequency of extremes near Los Angeles
(Swain 2019)

- Large projected increase in regional precipitation variability
- Asymmetric change in precipitation distribution: larger increase in wet extremes vs. dry extremes

Daniel Swain
dlswain@ucla.edu
www.weatherwest.com
@Weather_West

Changing *character* of precipitation in a warming world



Adapted from Pendergrass et al. 2017

- Global mean precip increases ~2-3% per degree C
- Extreme precip magnitude increases 5-10% per degree C (!)
- Extreme precip *frequency* increases by >>10% per degree C (!!)

Daniel Swain
dlswain@ucla.edu
www.weatherwest.com
@Weather_West

Why care about precipitation whiplash?


Thomas Fire,
Ventura County
Dec 2017

Debris flows,
S. Barbara County
Jan 2018

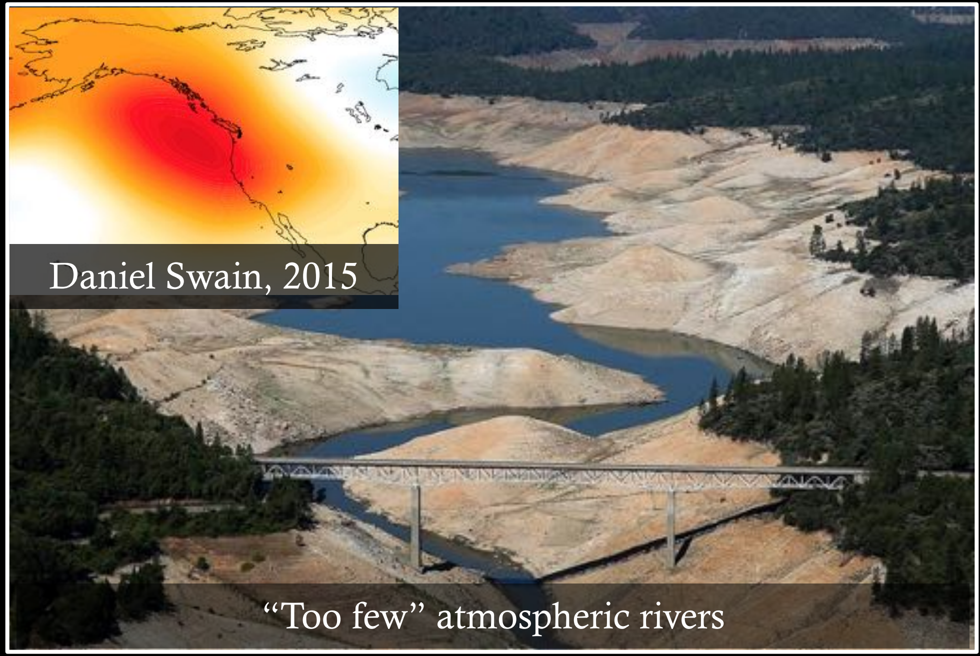

On average, it was mostly sunny and breezy—with below-average precipitation

If we only consider changes in average climate,
then we're largely missing the point.

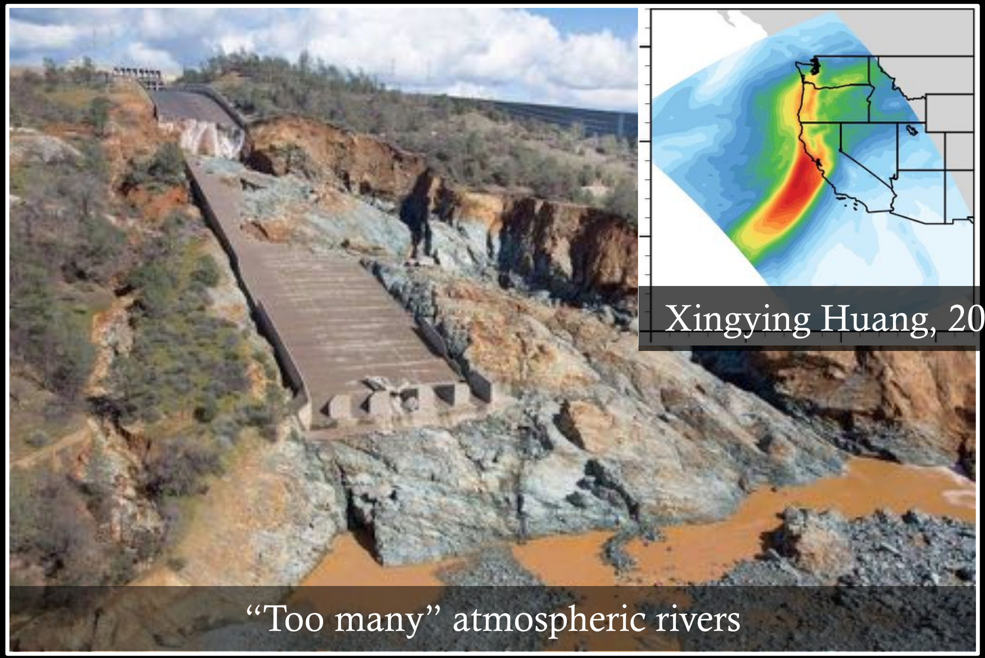
Daniel Swain
dlswain@ucla.edu
www.weatherwest.com
@Weather_West

Case study: wild swings between drought and flood at Oroville

Lake Oroville, September 2015



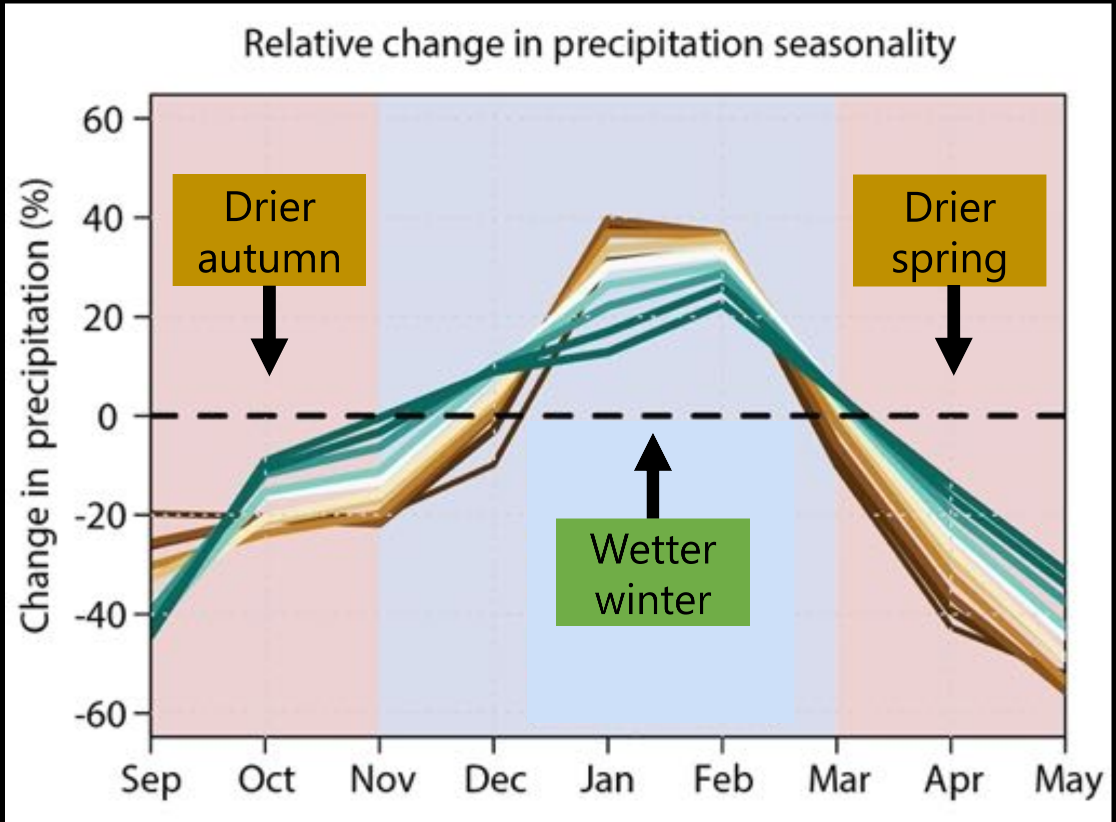
Oroville Dam, February 2017



- Weather/climate did not "cause" crisis. *However…*
- Extreme atmospheric river storm turned an engineering issue (failure of primary spillway) into crisis (headward erosion on emergency spillway)
- Historical warming increased Oroville inflows by ~30%. What about the future? (Huang et al. 2018 (runoff), Swain et al. 2018 (precip))

Daniel Swain
dlswain@ucla.edu
www.weatherwest.com
@Weather_West

An (even) shorter, (even) sharper rainy season



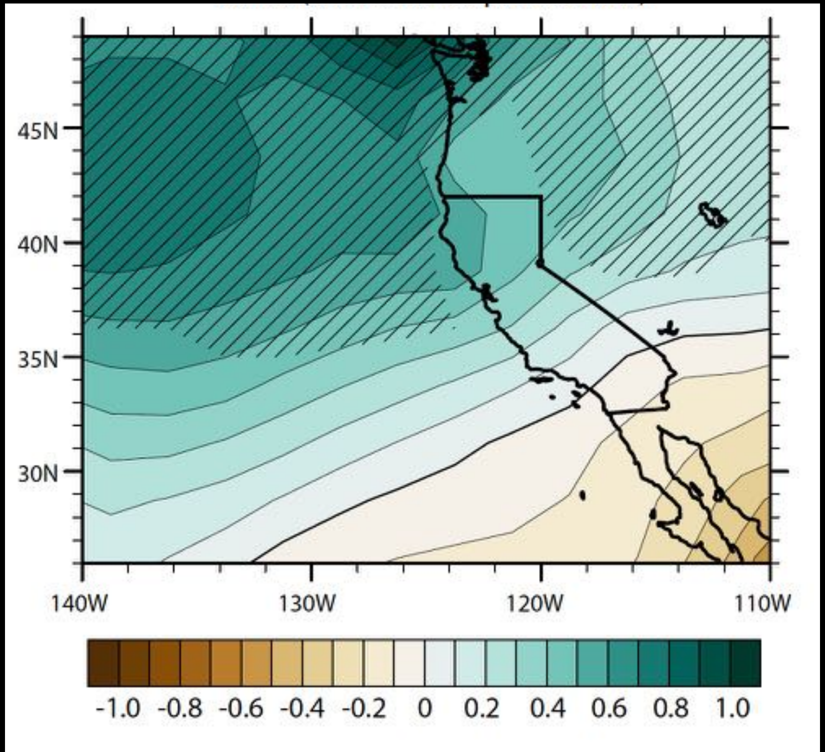
Swain et al. 2018

- Drying trends in autumn & (especially) spring, strongest south
- Further "narrowing" of rainy season (w/modestly wetter winters)
- Key implications: wildfire risk, snowpack, ecosystem stresses, agriculture

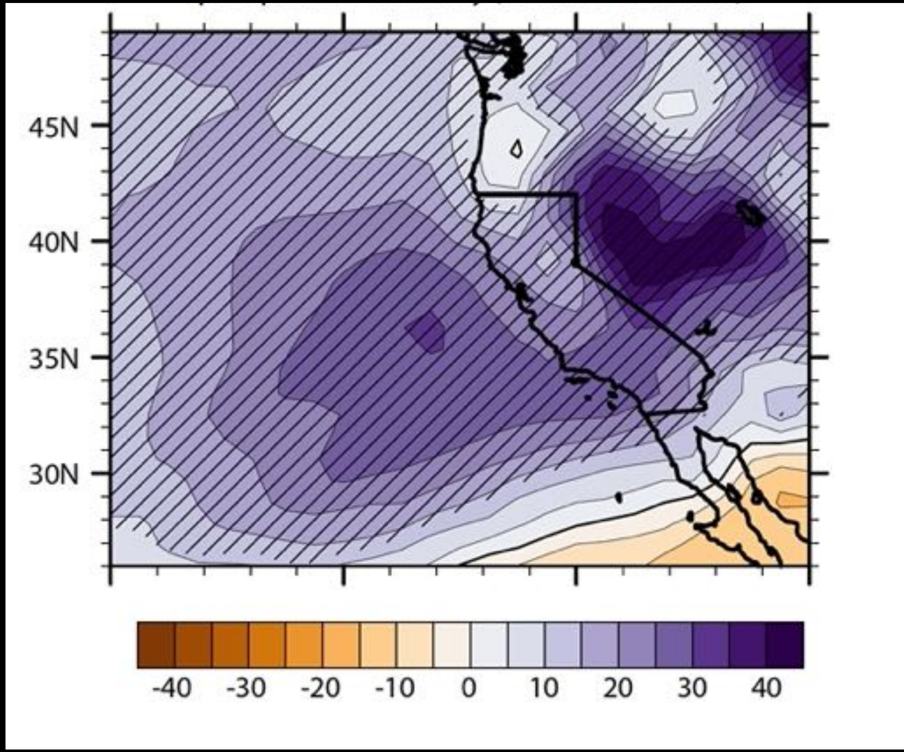
Daniel Swain
dlswain@ucla.edu
www.weatherwest.com
@Weather_West

Changes in mean vs. variability, north vs. south

Future winter mean precip change, CMIP5



Future winter precip variability change



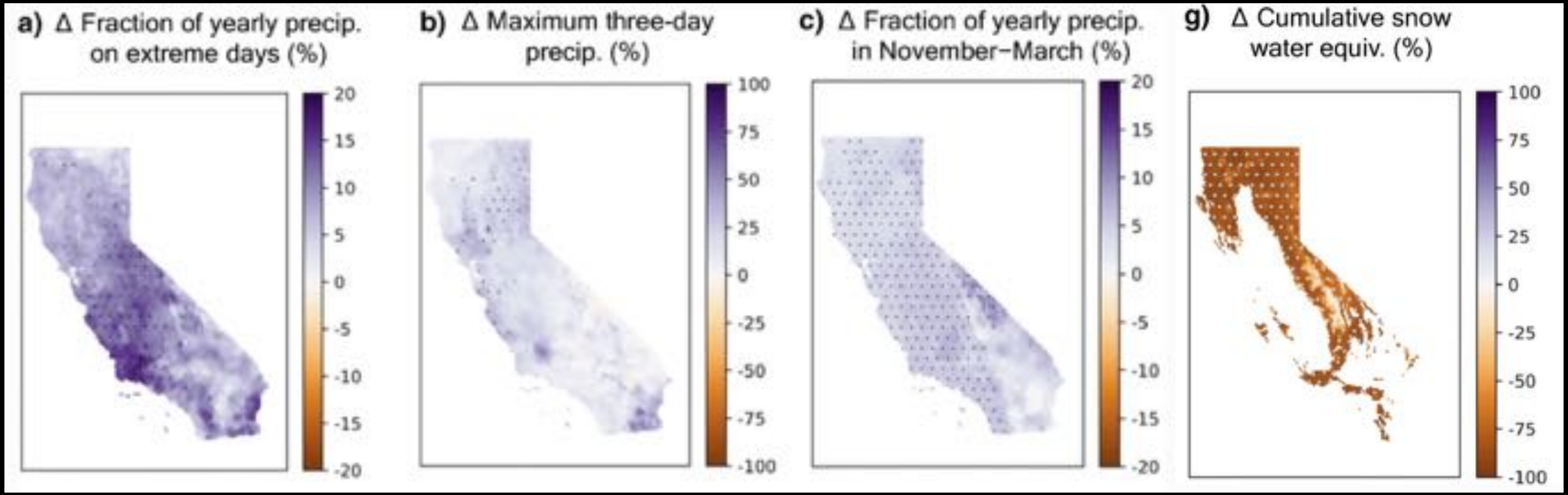
Swain et al. 2018

- Modest change in mean winter precip statewide, but possible slight increase
- On annual basis, avg changes small (slightly negative south, positive north)
- Substantial increase in variability statewide, even within winter!

Daniel Swain
dlswain@ucla.edu
www.weatherwest.com
@Weather_West

A paradox: simultaneously increasing water scarcity and overabundance

Large changes in non-mean precipitation characteristics

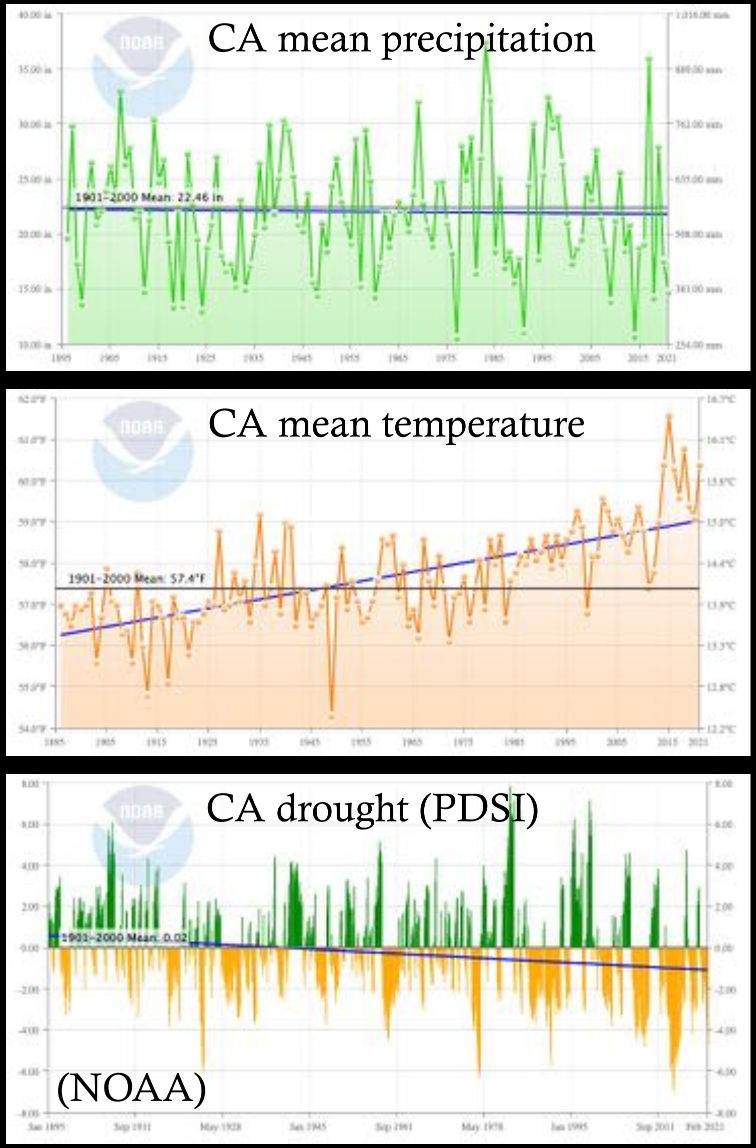


Persad et al. 2020

- Less autumn/spring precipitation, but more winter precipitation
- More precipitation on fewer days, with more intense (but fewer?) storms
- Dramatically less snowpack, but more evaporation
- All of this put together = increased risk of drought *and* flood

Daniel Swain
dlswain@ucla.edu
www.weatherwest.com
@Weather_West

Temperature increasingly dominating as driver of drought in warming climate



- Precipitation-only drought metrics are becoming increasingly misleading in a warming climate
- The same amount of rain/snow just doesn't go as far as it used to due to increasing evaporative demand
- Precip phase: liquid rain vs. solid snow?
- Spatiotemporal *character* of precipitation also matters, as well as overall amount. (Shifting seasonality? Shorter, sharper bursts? More runoff, but less infiltration?)

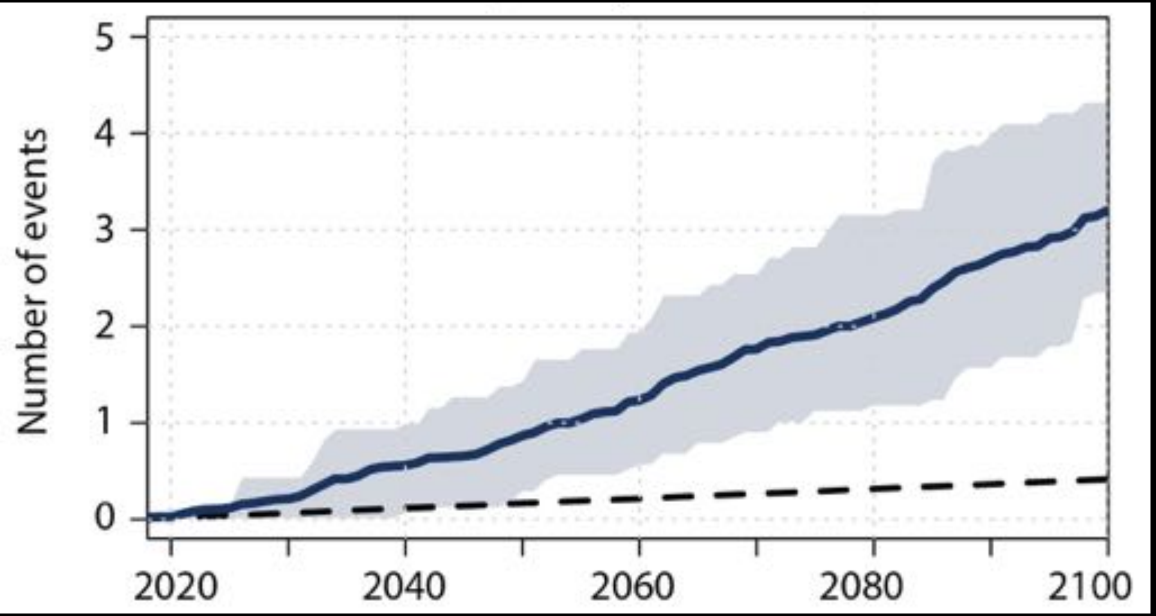
Daniel Swain
dlswain@ucla.edu
www.weatherwest.com
@Weather_West

California's "Other Big One": Month-long atmospheric river deluge

Downtown Sacramento, Jan 1862

San Francisco Chronicle

Cumulative likelihood of "1862-like" event



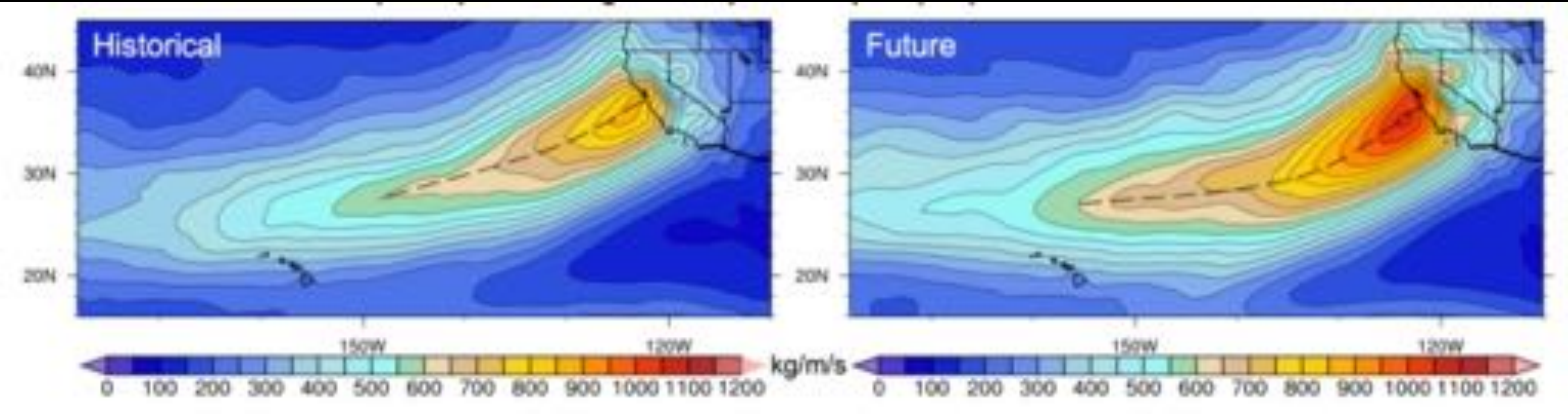
Swain et al. 2018

- California "great floods" have occurred every ~200 years
- Modern day repeat would be disastrous for California
- Greater than 50% risk of an 1862-level in next ~40 years (!)

Daniel Swain
dlswain@ucla.edu
www.weatherwest.com
@Weather_West

Stronger, moister atmospheric river storms

Water vapor transport during extreme atmospheric river storms



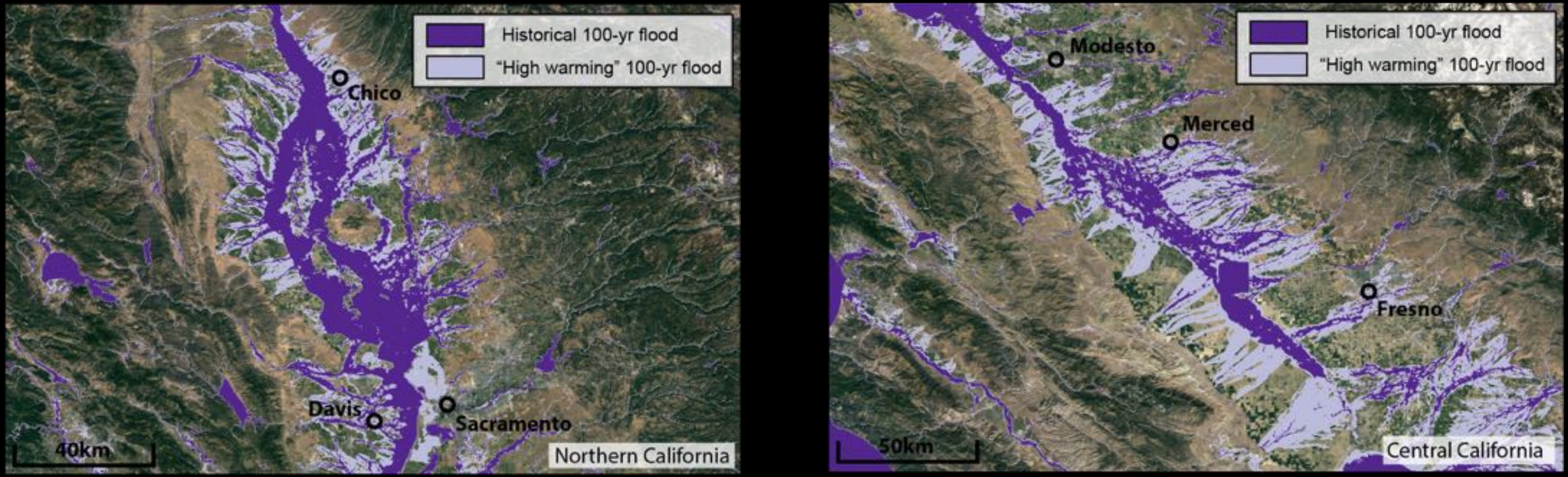
Huang et al. 2020

- Substantial increase in atmospheric river strength due to climate change, mainly due to warming-driven increase in atmospheric moisture. Occurrence of historically "unprecedented" events.

Daniel Swain
dlswain@ucla.edu
www.weatherwest.com
@Weather_West

California flood risk looms large in warming climate

20th century vs. warmer future "100 year flood" footprint



Swain et al. 2020

- Climate change likely to increase risk broadly, but CA is a hotspot
- Widespread/deep inundation possible in highly populated areas
- How, exactly, will flood protection infrastructure fare in a "megastorm?"
  - Not just mainstem rivers, but urban tributaries?
  - Dam structural problems: low probability but high consequence events

Daniel Swain
dlswain@ucla.edu
www.weatherwest.com
@Weather_West

Wildfire as a complex Earth system process


Low-intensity smoldering fire


High-intensity crown fire

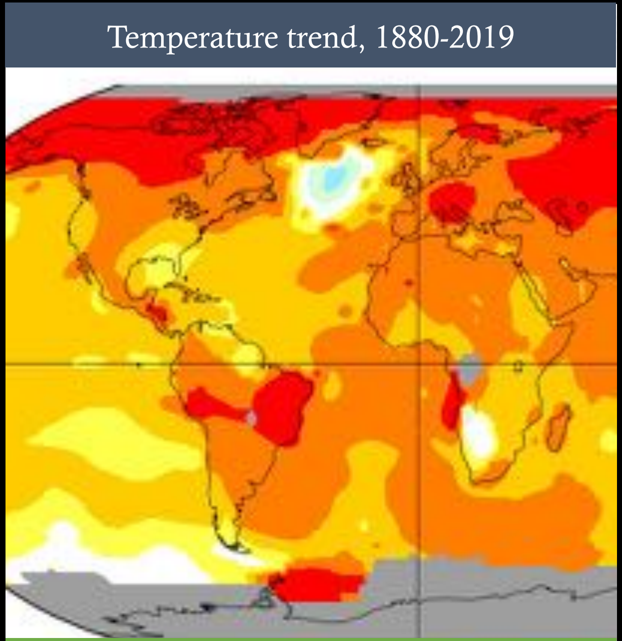
- Wildfires fueled primarily by vegetation (forests, grasslands, and everything in between) and are a natural process
- Susceptibility to wildfire a function of both background climate and local vegetation conditions (both of which vary over time)
- Not all wildfires are created equal: high vs. low intensity; uniform vs. mosaic burn pattern; fire adapted ecosystems, etc.

Daniel Swain
dlswain@ucla.edu
www.weatherwest.com
@Weather_West

What is driving the escalating wildfire crisis? The three pillars:

Expansion into high-risk fire zones

Legacy of 20th century "total fire suppression"



Climate change

Daniel Swain
dlswain@ucla.edu
www.weatherwest.com
@Weather_West

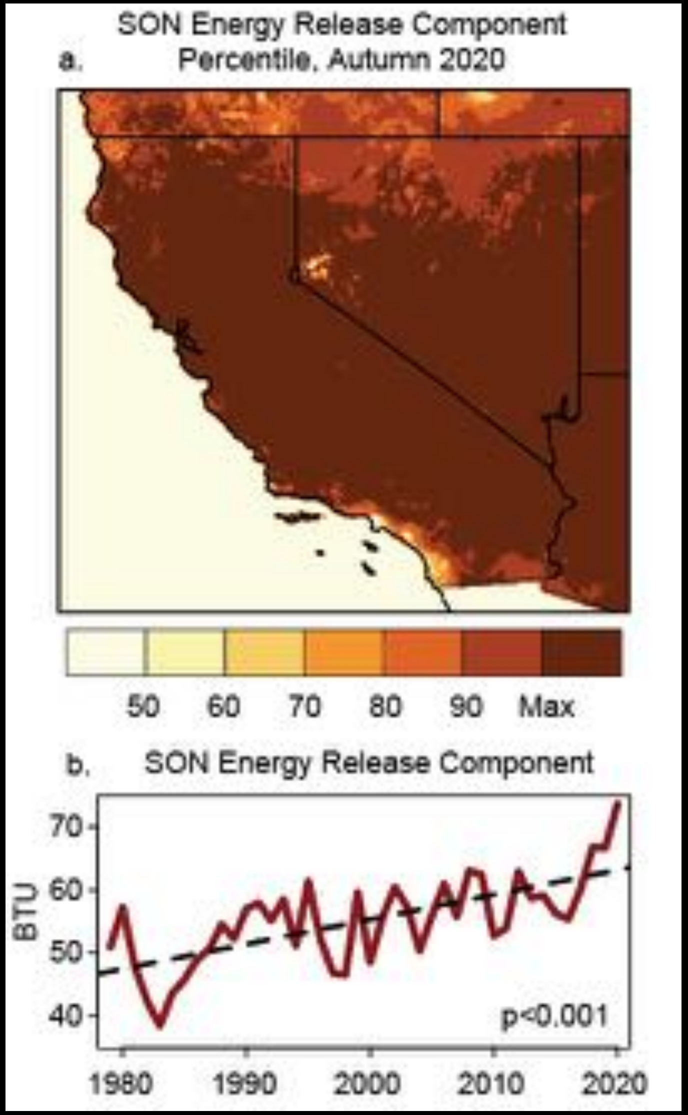
Role of warming and "aridification"

- As temperatures rise, so does gap between how much water is actually in the air and how much *could be* in air (increasing vapor pressure deficit)

- Increasing atmospheric water "demand" plus increased soil H20 depletion due to warming lead to drying of vegetation

- >50% of observed increase in Western U.S. forest fire area burned can be *directly* attributed to effects of warming/drying

Vegetation flammability

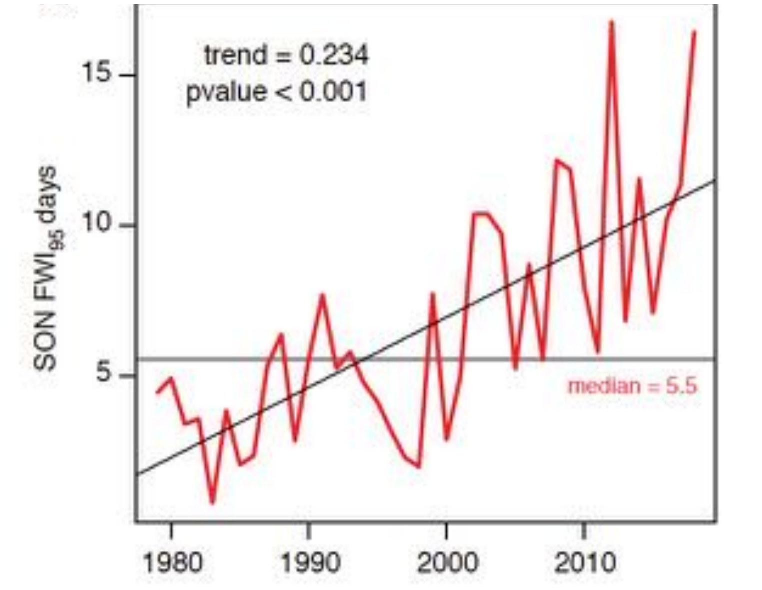


Adapted from Swain 2021

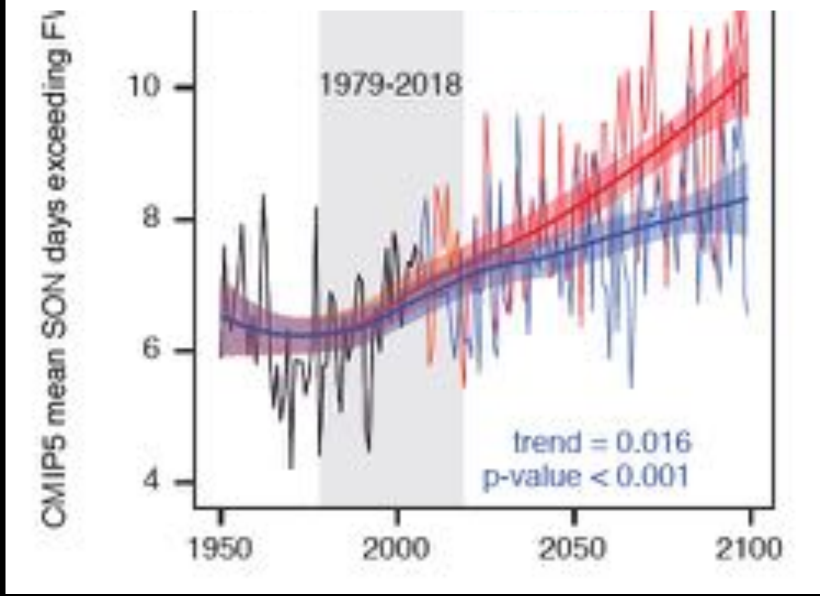
Daniel Swain
dlswain@ucla.edu
www.weatherwest.com
@Weather_West

Climate change is making wildfires larger, more intense, and more dangerous

Observed CA extreme fire weather trend



21st century projected fire risk



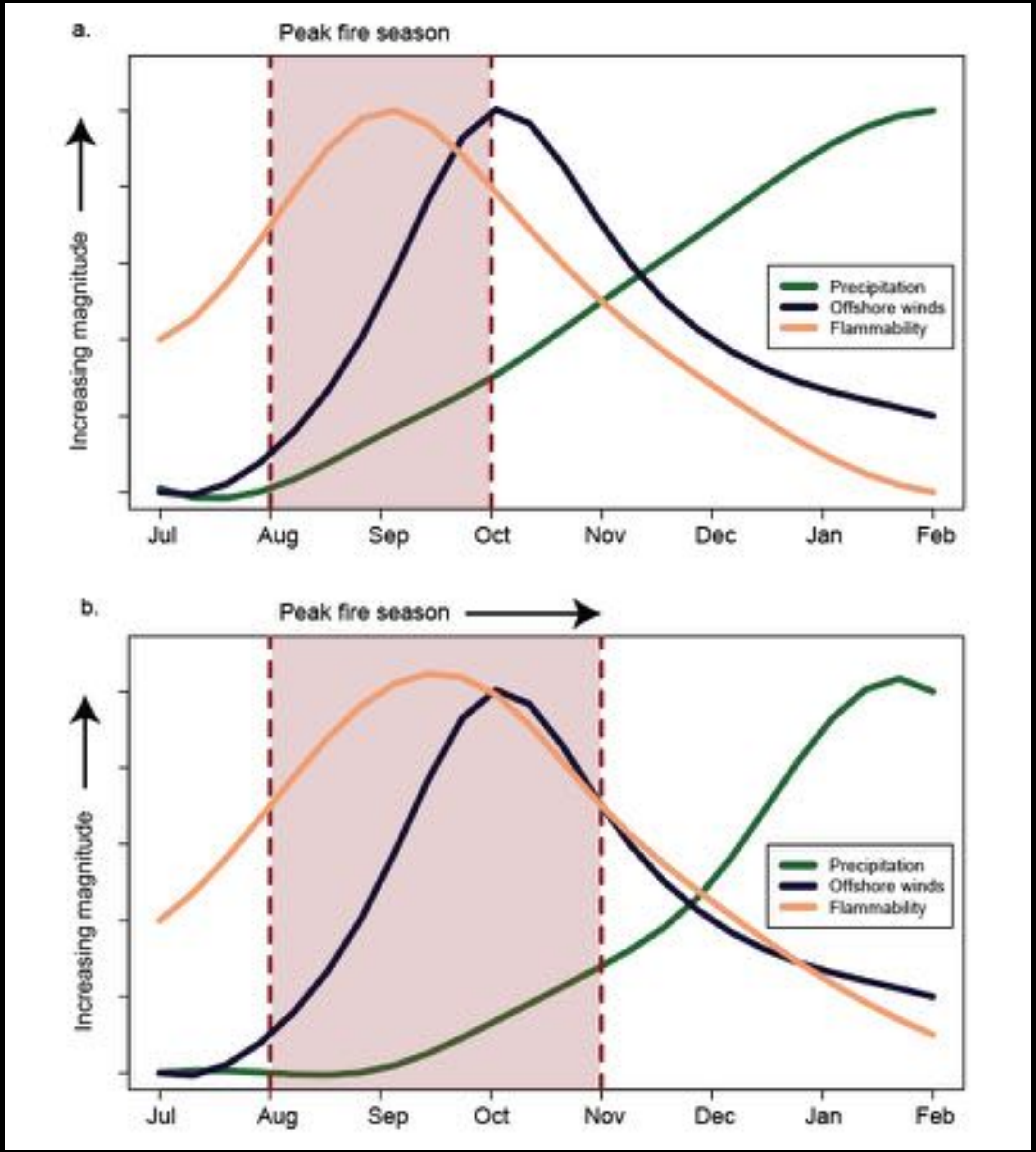
Goss et al. 2020

- In California, climate change has *already* more than doubled occurrence of extreme fire weather conditions between 1980-2018
- Climate change is changing *character* of wildfire (rather than #)
- Why? Key mechanism is warming air & drying of vegetation

Daniel Swain
dlswain@ucla.edu
www.weatherwest.com
@Weather_West

CA wildfire risk: Seasonality matters

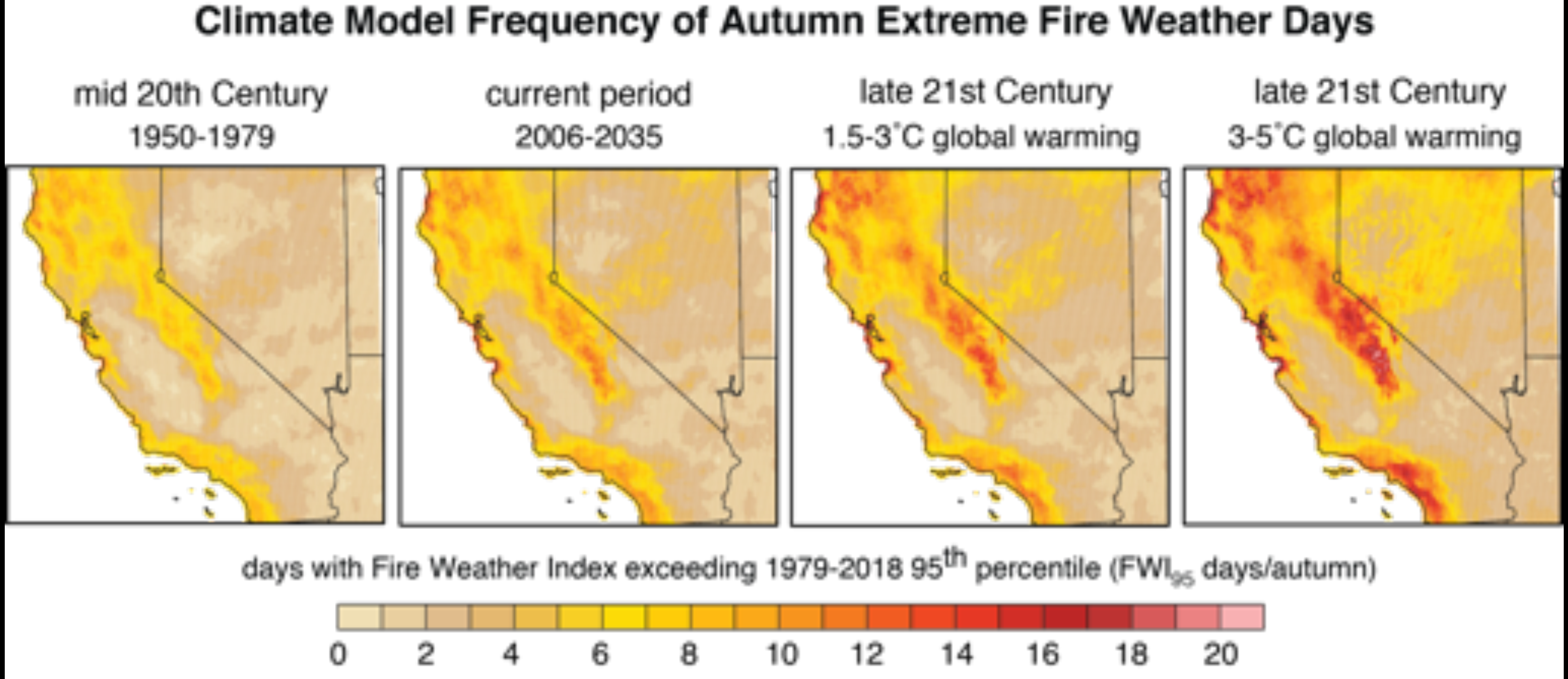
Increased overlap between peak vegetation dryness and offshore wind season with delayed rainy season onset



Swain 2021
in response to
Luković et al. 2021

Daniel Swain
dlswain@ucla.edu
www.weatherwest.com
@Weather_West

A "new abnormal" for California wildfire



Adapted from Goss et al. 2020

- Further warming in California is inevitable (but how much?)
- Climate component of wildfire risk will get worse before better
- Implications: post-fire debris flows/floods, water quality issues

Daniel Swain
dlswain@ucla.edu
www.weatherwest.com
@Weather_West

And it's not just California: The changing character of Western wildfire

Extreme fire behavior & large fire vortex on Calwood Fire near Boulder, CO on Oct 17, 2020.
Video by Daniel Swain.

Daniel Swain
dlswain@ucla.edu
www.weatherwest.com
@Weather_West

Catastrophic fire in wildland-urban interface: An accelerating crisis, but not inevitable

Tubbs Fire, 2017

Camp Fire, 2018

LNU Complex, 2020

Wildfire is not inherently bad. But its intersection with populated areas has become increasingly catastrophic, and still worse is possible in future. How can we decouple fire from catastrophe?

Daniel Swain
dlswain@ucla.edu
www.weatherwest.com
@Weather_West

To cope with increasing drought, flood, & fire, flexible adaptations will be key


Yolo Bypass (in flood) near Sacramento


Prescribed burn on Yurok tribal land

- Physical reality: increase in both precip intensity *and* overall aridity, dramatic loss of snowpack, longer & more intense fire seasons
- It's becoming abundantly clear that historical paradigms and management practices aren't going to cut it in 21st century.
- Can we mitigate flood & drought risk simultaneously, and fight (bad) fire with (good) fire? The promise of FloodMAR and prescribed burning.

Daniel Swain
dlswain@ucla.edu
www.weatherwest.com
@Weather_West

Closing thoughts

- Climate change has arrived, and California is already a different place than when 20th century policies & infrastructure were developed.

- Plausible trajectory: warmer year round w/much less snow, more intense but less frequent storms, and narrowing wet season. Longer fire season, with larger & more intense fires.

- Large further increases in wildfire & flood risk plausible. How to de-couple these increases in physical hazards from catastrophe?

- Physical science suggests that we will need be flexible in face of increasing extremes. We won't always be able to build our way out of challenges in a warming climate.

Daniel Swain
dlswain@ucla.edu
www.weatherwest.com
@Weather_West

Thank you! To contact me:

Email: dlswain@ucla.edu
Blog: www.weatherwest.com
Twitter: @Weather_West

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