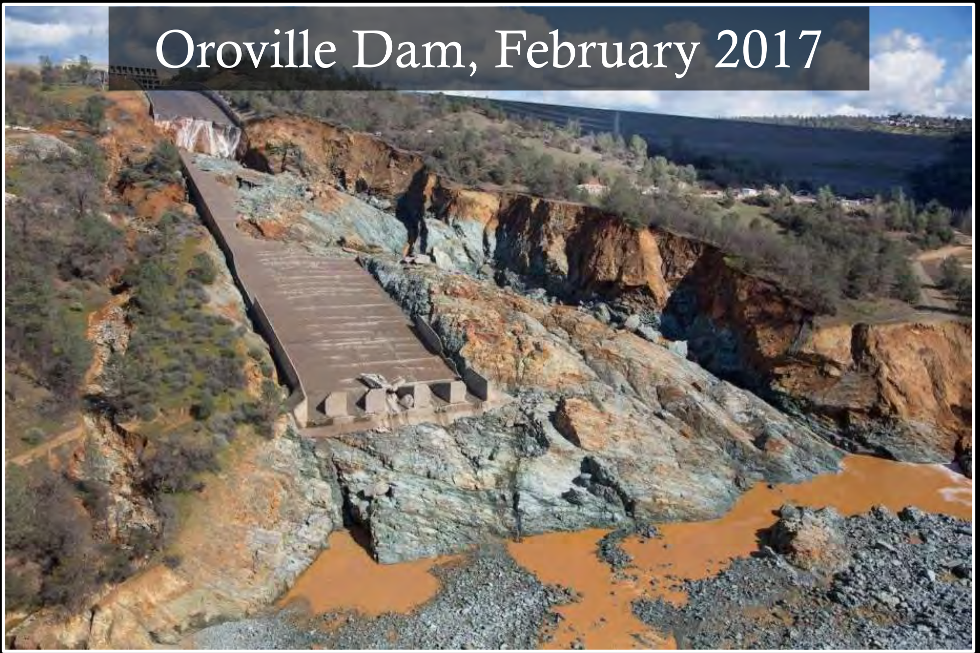
Southern California Water Dialogue

The Future We Worried About is Here

March 23, 2022

Drought, flood, and precipitation whiplash in a warming California


Oroville Dam, February 2017


Camp Fire, November 2018

Daniel Swain

UCLA, NCAR, The Nature Conservancy

Southern California Water Dialogue

March 2022

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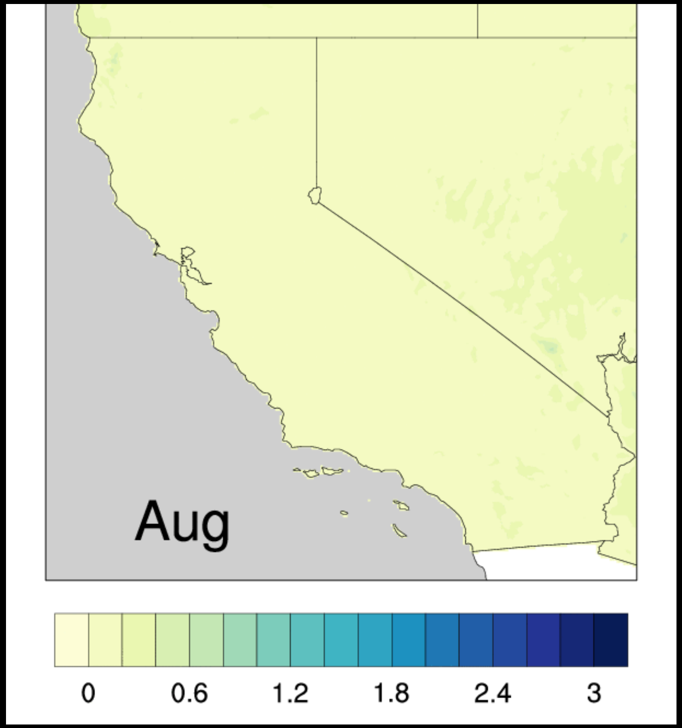
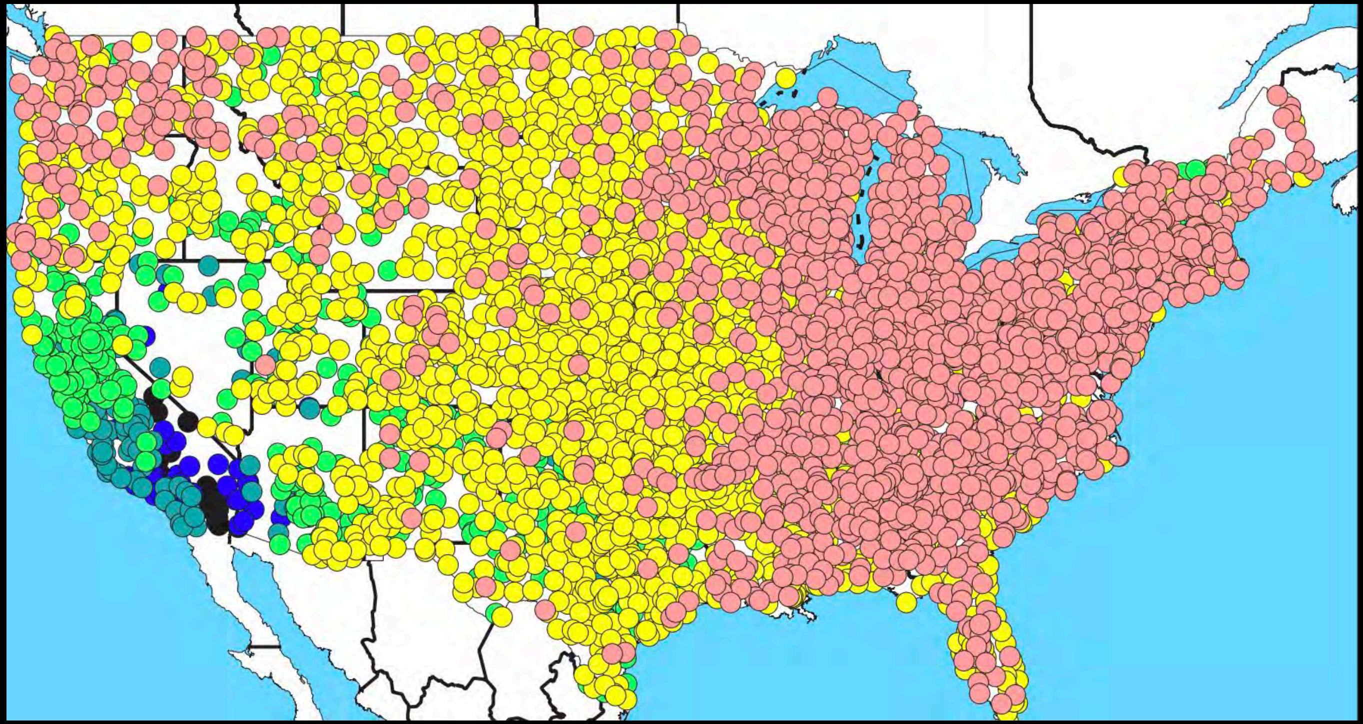
Primer: California's unusual climate context

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

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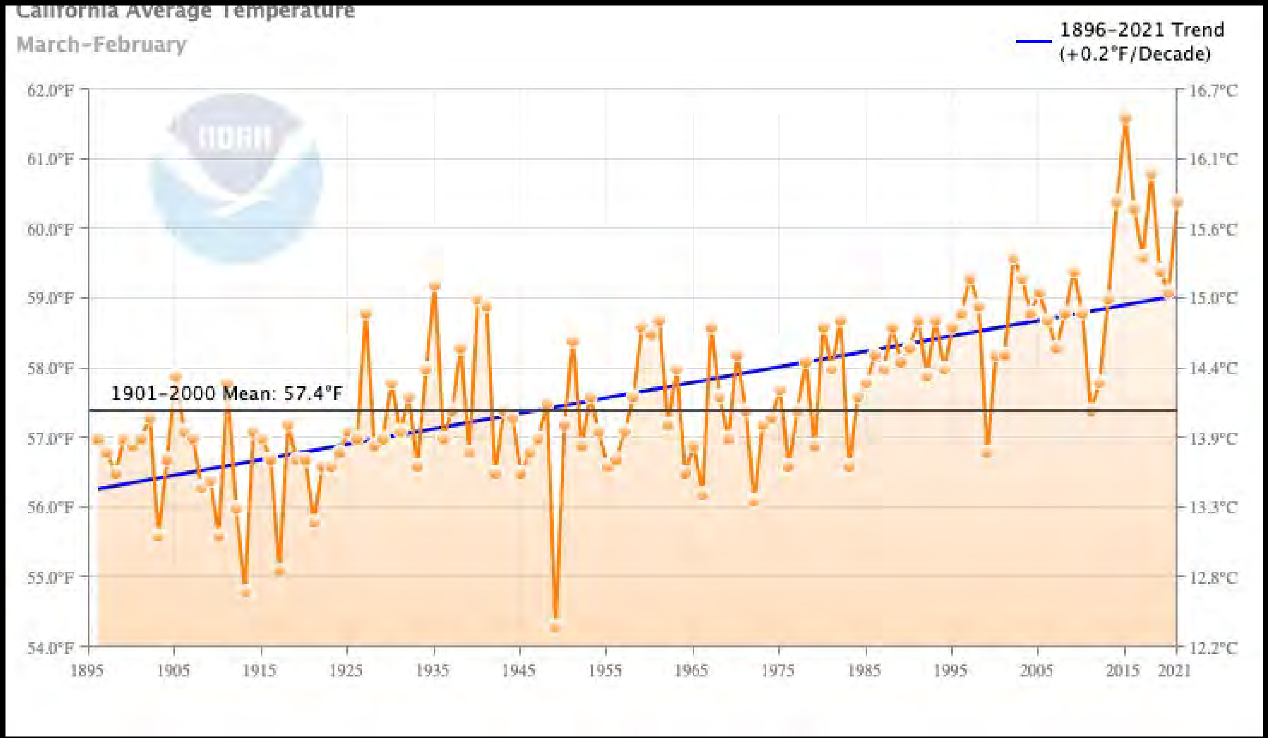
California changes so far: warmer, less snow, more flammable

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

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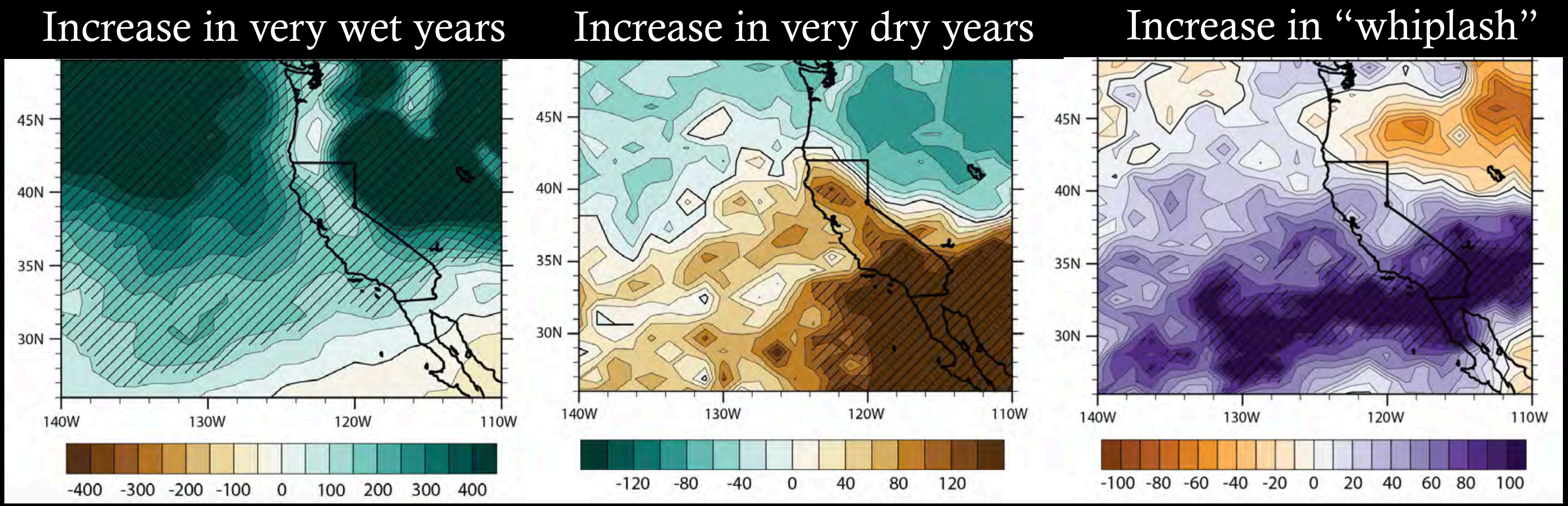
A wetter *and* drier future?



Swain et al. 2018

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

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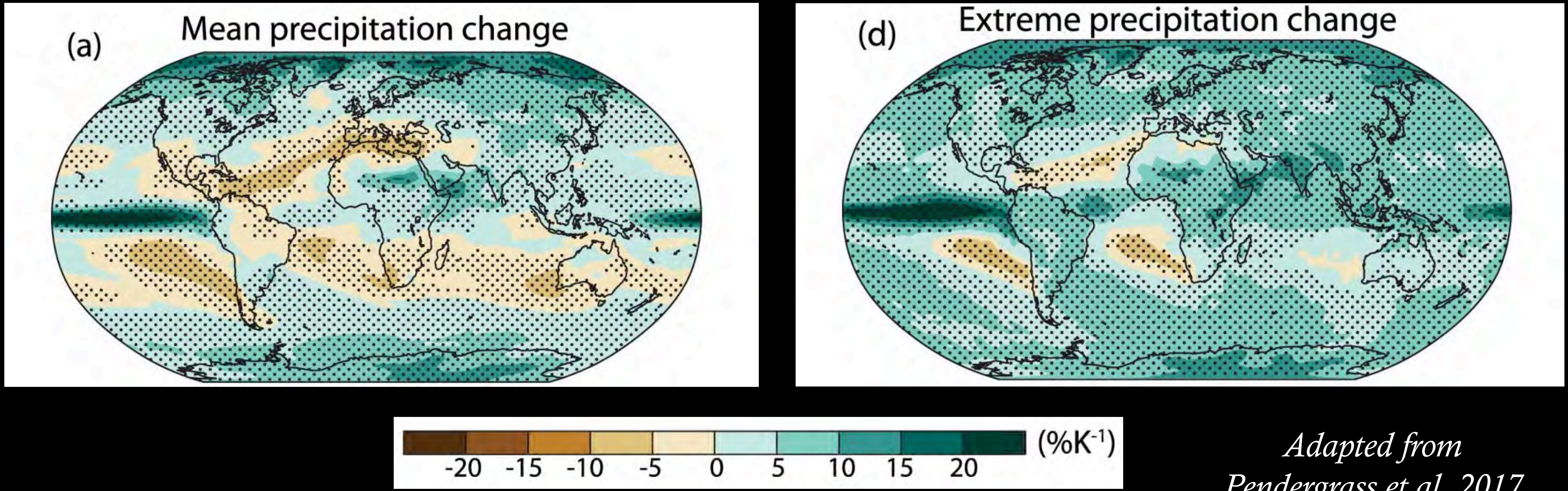
Changing *character* of precipitation in a warming world



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 (!!)

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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.

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Case study: wild swings between drought and flood at Oroville

Lake Oroville, Sep. 2015

"Too few" atmospheric rivers…

Oroville Dam, Feb. 2017

"Too many" atmospheric rivers…

Lake Oroville, Jul. 2021

…and back again.

- Extreme, record-breaking drought in 2014-2015
- Then, extreme atmospheric river storm sequence turned an engineering issue (failure of primary spillway) into broader crisis.
- Right back to extreme/record-breaking drought in 2021
- CA no stranger to extremes—but growing amplitude pushing infrastructure to brink

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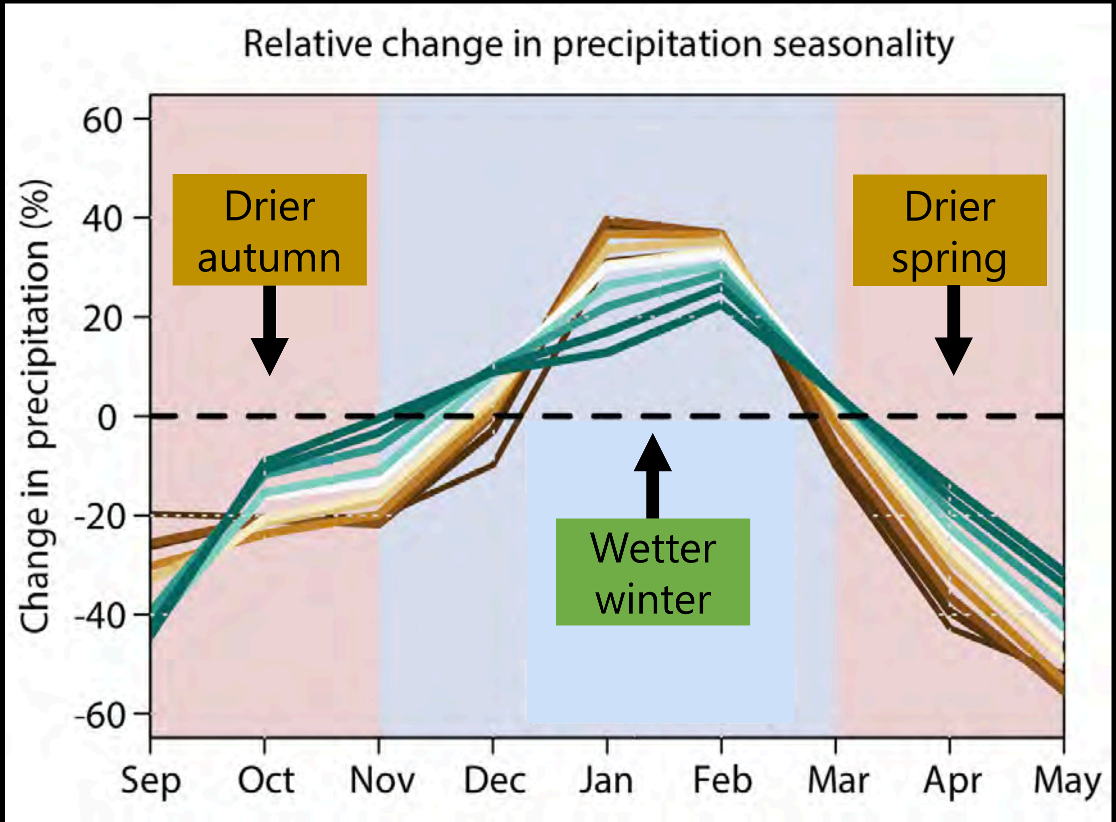
An (even) shorter, (even) sharper rainy season



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

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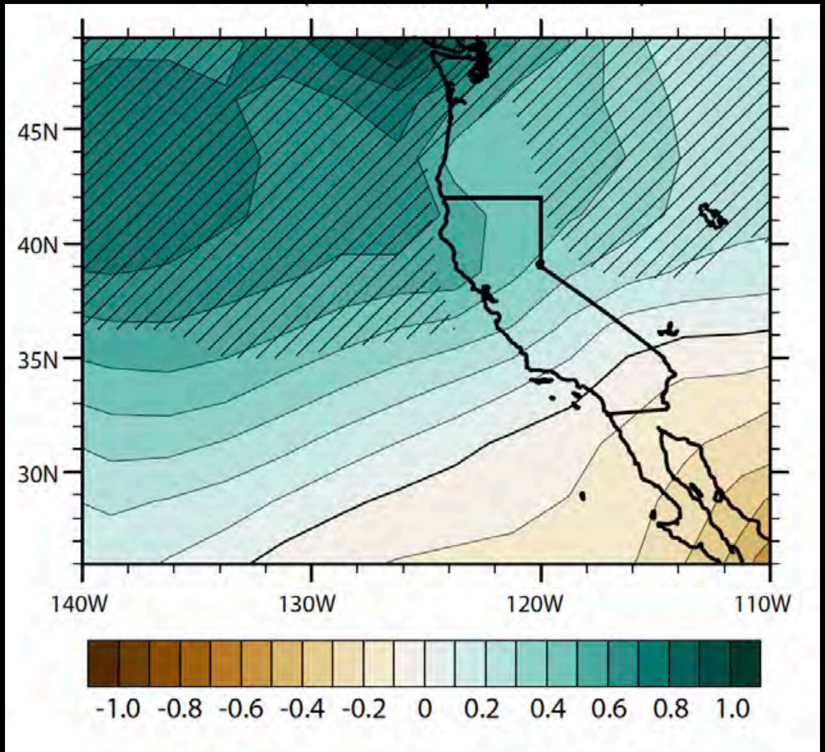
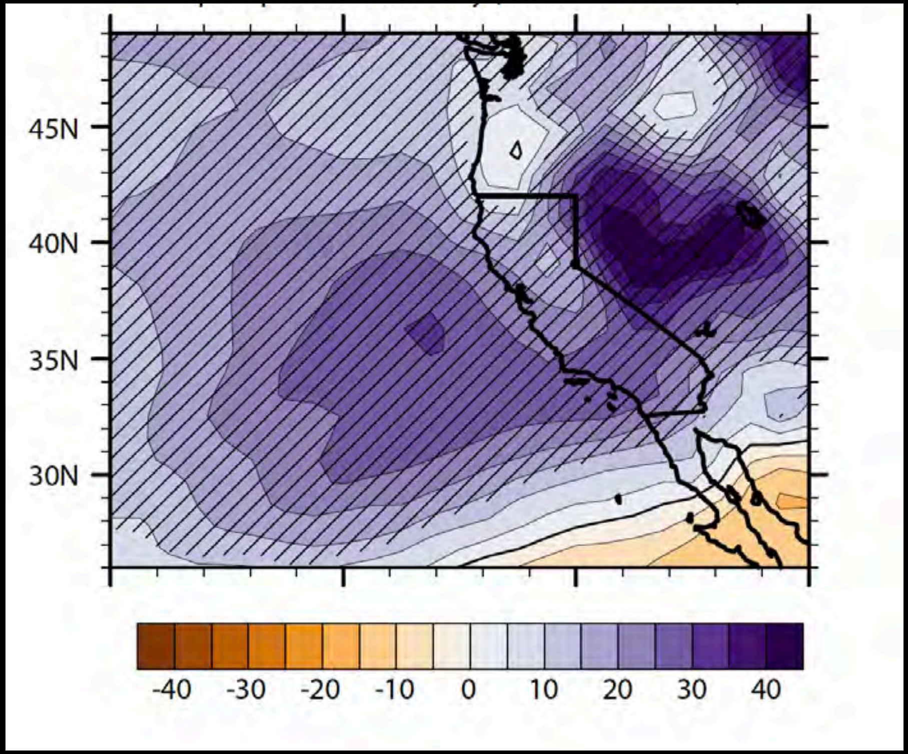
Changes in mean vs. variability, north vs. south

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!

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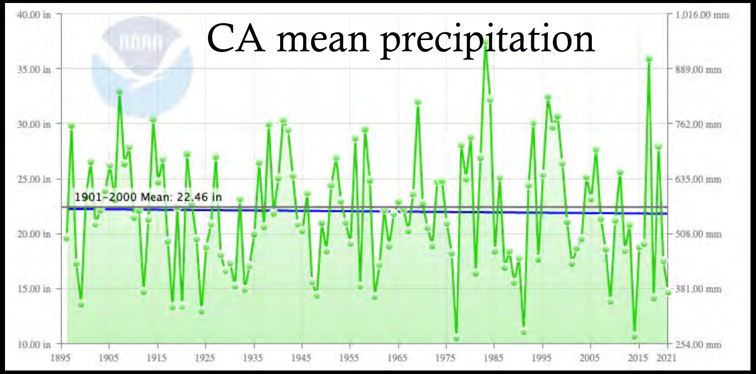
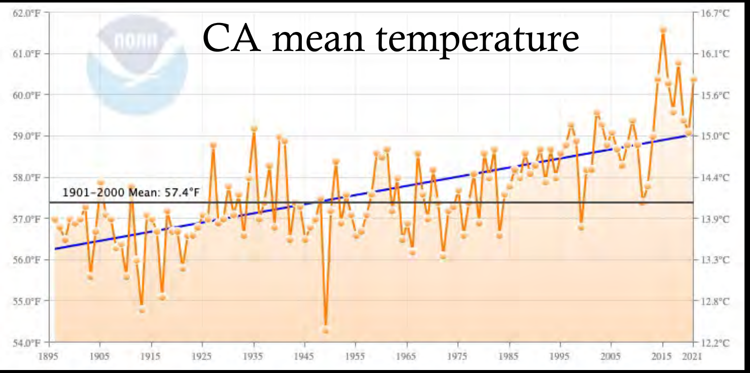
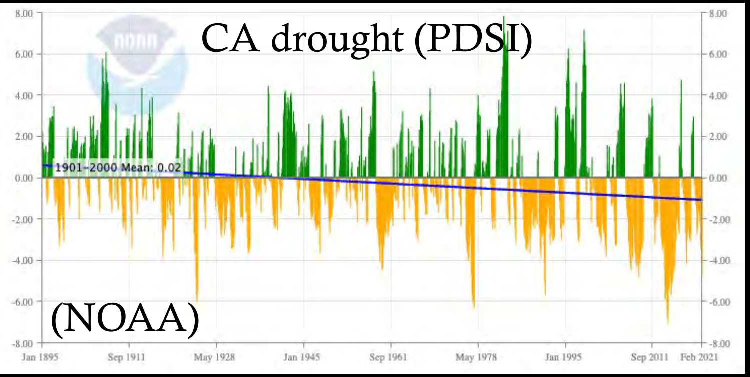
Longer, more severe droughts… yet little decrease in *average* precipitation?







- 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
- Less autumn/spring precipitation, but more winter precipitation
- More precipitation on fewer days, with more intense (but fewer?) storms
- Much less snowpack, but more evaporation

- All of this put together = increased risk of drought *and* flood

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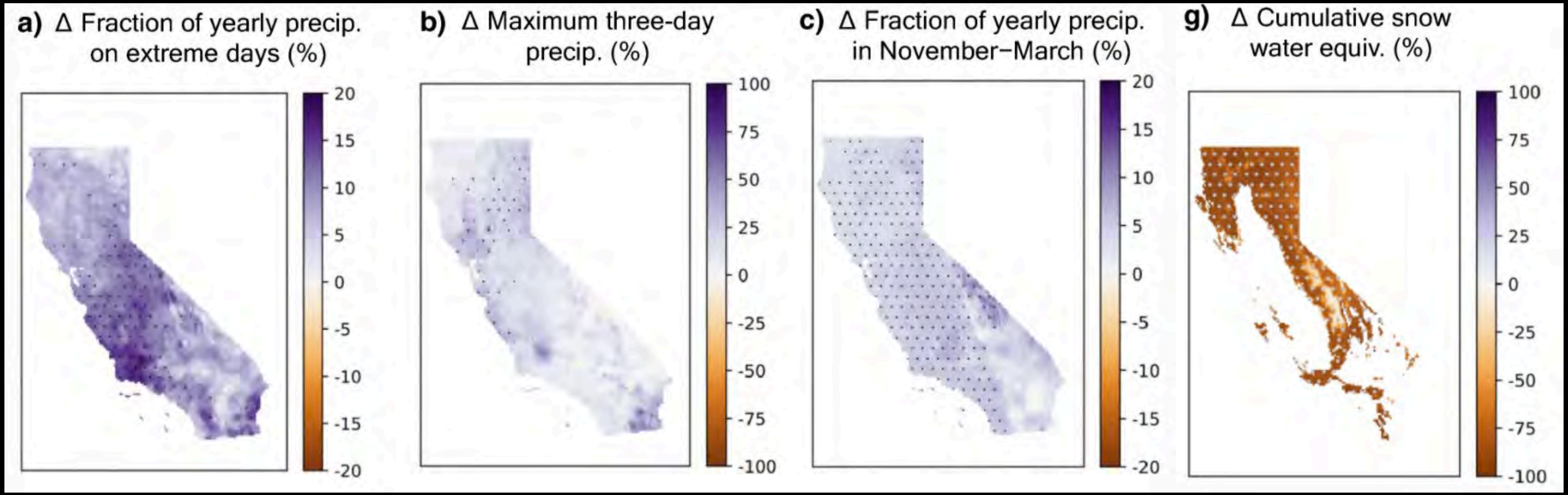
A paradox: simultaneously increasing water scarcity and overabundance

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

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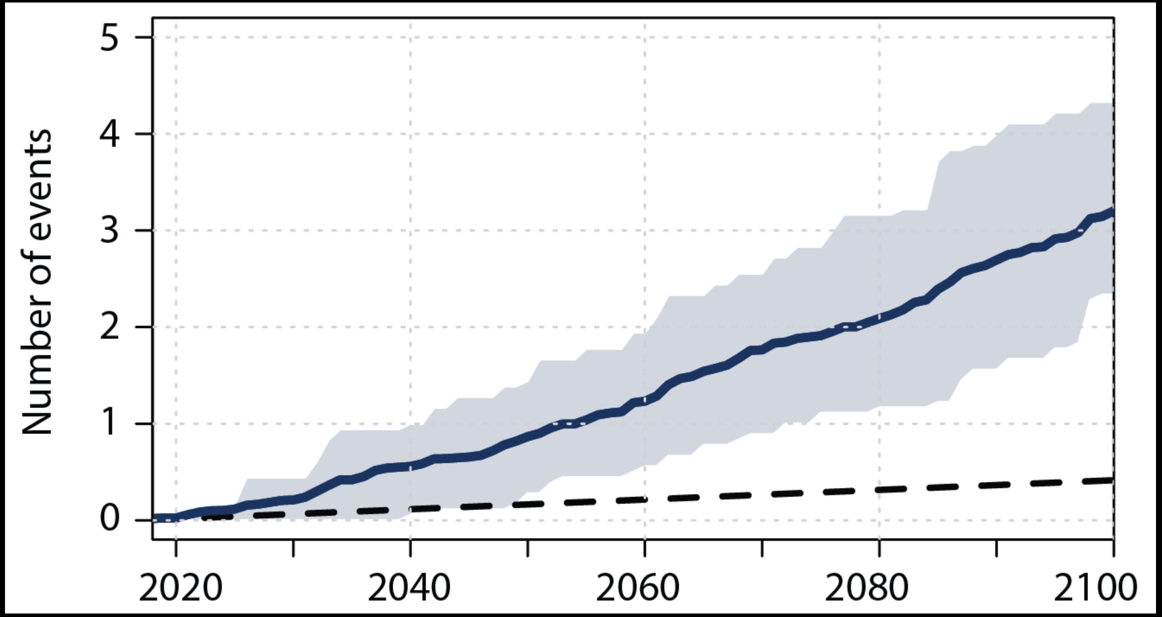
California's "Other Big One": Month-long atmospheric river deluge

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 (!)

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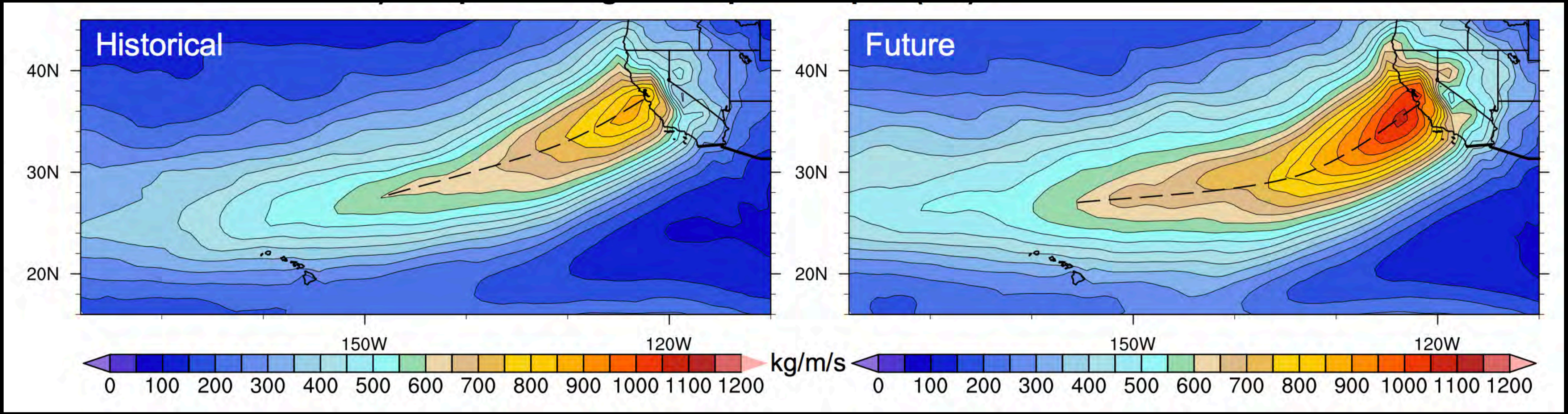
Stronger, moister atmospheric river storms

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.

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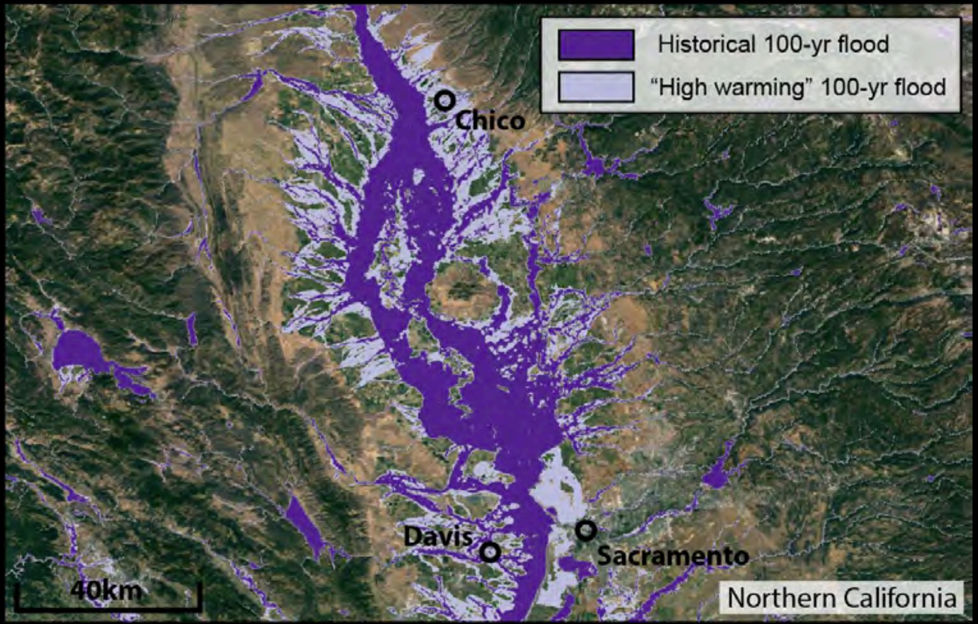
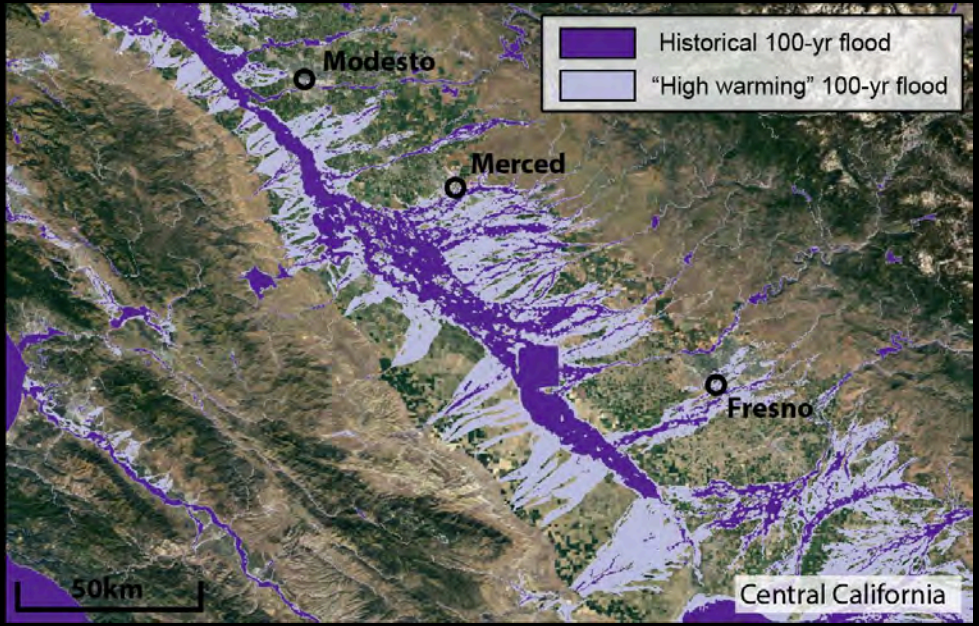
California flood risk looms large in warming climate

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

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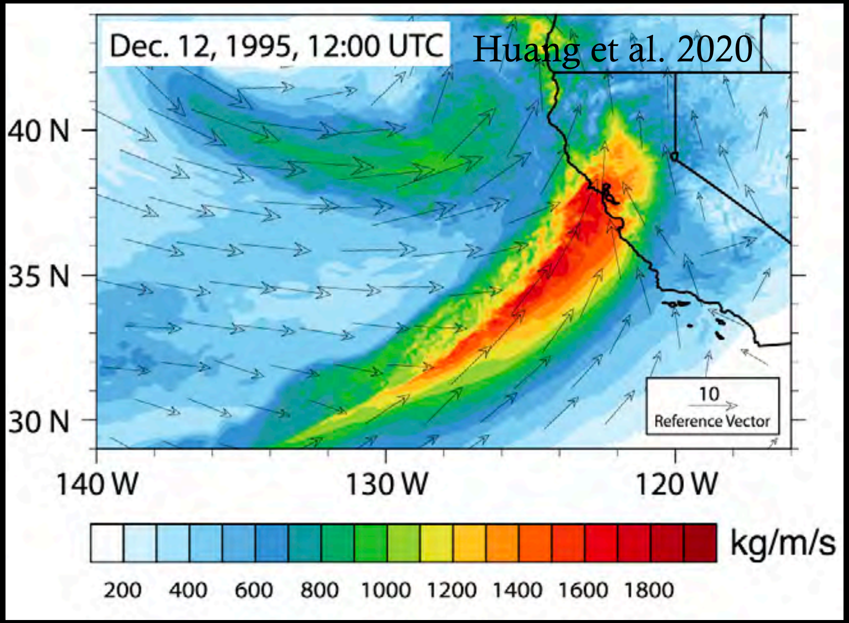
ARkStorm 2.0: a new and improved extreme flood scenario for 21st century California



Collaborators include:
Daniel Swain (UCLA)
Xingying Huang (NCAR)
Dale Cox (USGS)
Christine Albano (DRI)
Maureen McCarthy (DRI)
Mike Anderson (DWR)
Kathy Schaefer (UC Davis)
Among many others!

- ARkStorm 1.0: California-wide "megastorm" planning exercise
- ARkStorm 2.0 aims: factor in climate change, scientific advances of past decade, and lessons learned during Oroville/pandemic
- Project status: Initial atmospheric simulations complete! But funding still (urgently) needed to complete hydrologic component…

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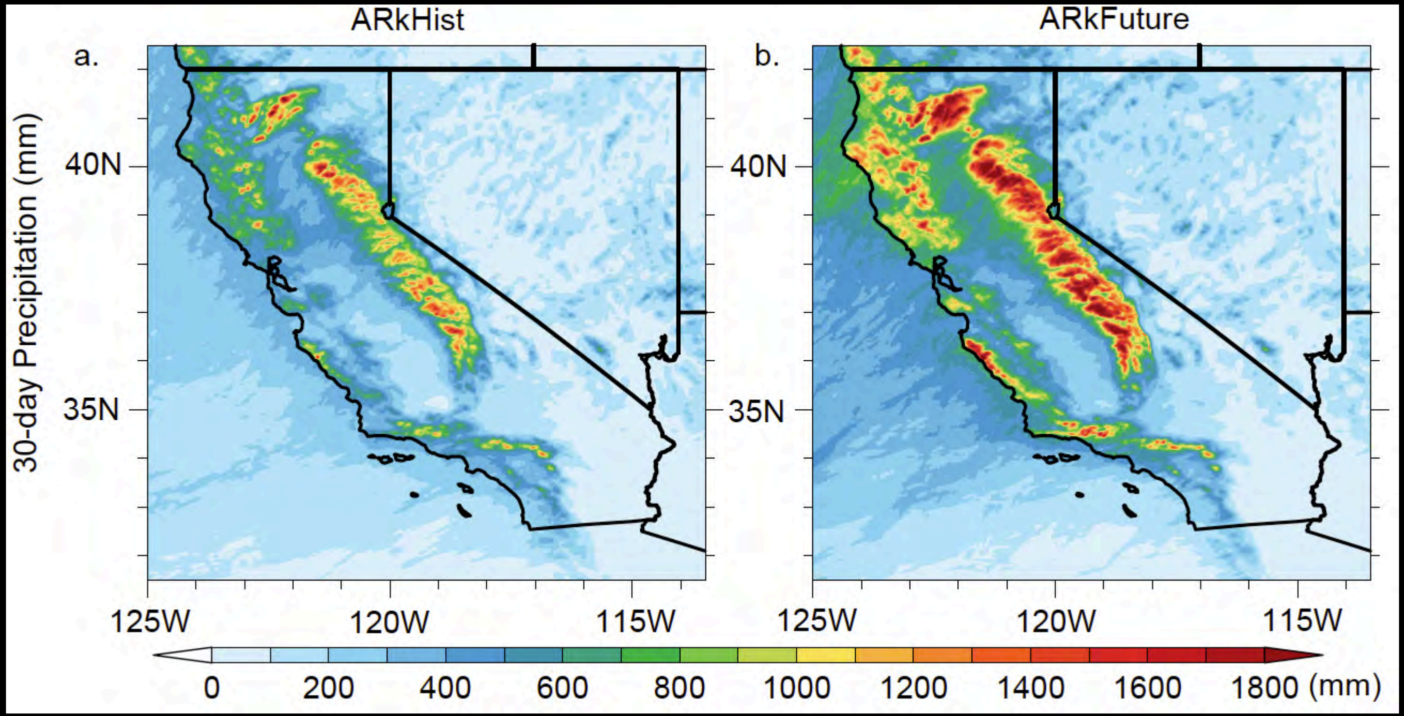
An early preview of ARkStorm 2.0 results



Huang and Swain 2022 (in review)

- Climate change has *already doubled* the risk of a widespread, statewide "100 year"/1% annual likelihood event! Also: large further risk increases with continued warming.
- Plausible worst case future runoff locally >200% higher than plausible worst case historical runoff

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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 beneficial, 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/dependent ecosystems, etc.

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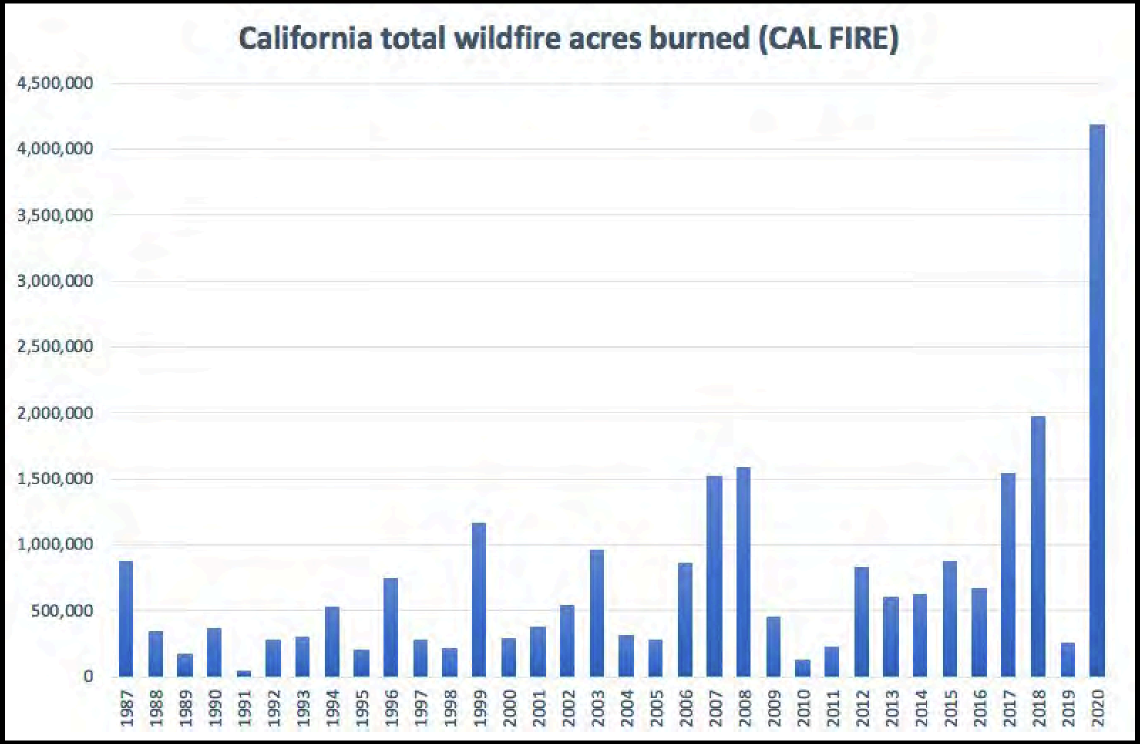
Dramatic recent increase in California wildfire

Since 2015 in California:

- 12 of 20 largest fires
  (6 in 2020)
- 15 of 20 most destructive fires
  (5 in 2020)
- 7 of 20 deadliest fires
  (2 in 2020)

More people have died in CA wildfires since 2017 than in any earthquake since SF "Great Quake" of 1906.



California wildfire extent, 1987-2020 (Cal Fire)

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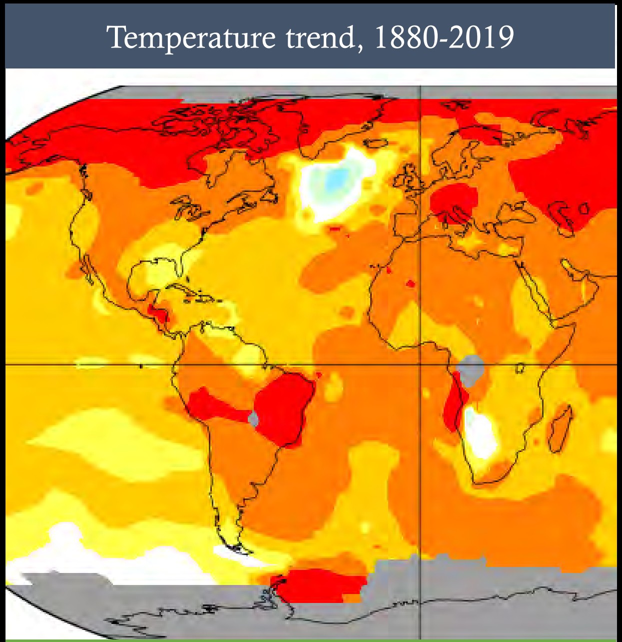
What is driving the escalating wildfire crisis? The three pillars:

Expansion into high-risk fire zones

Legacy of 20th century "total fire suppression"



Climate change

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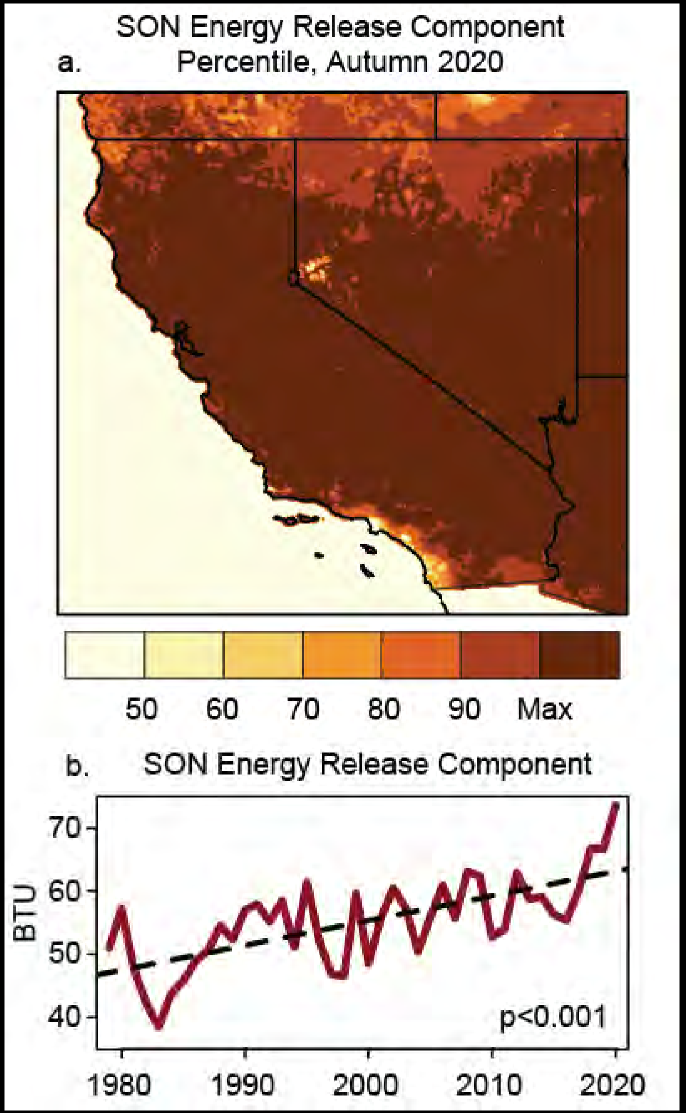
Role of warming and "aridification"

- 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 (dead and living)

- >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

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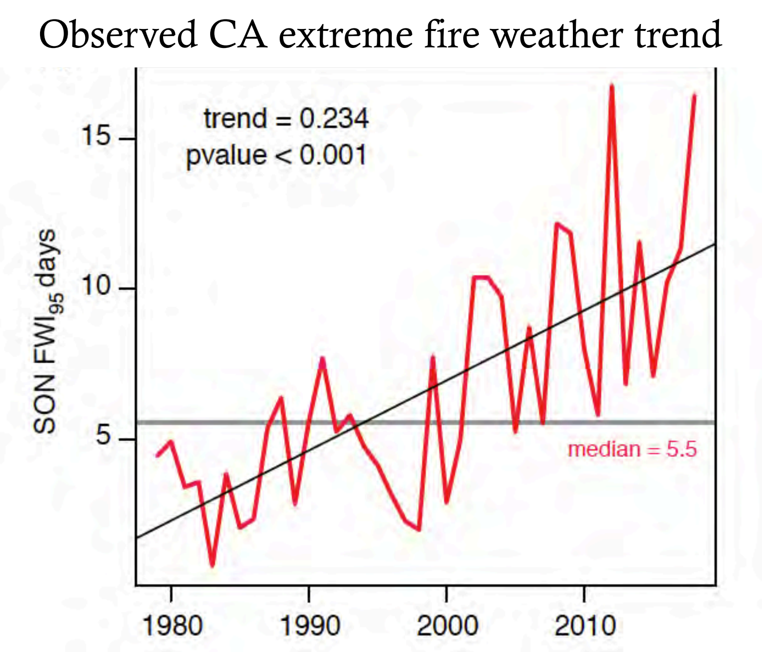
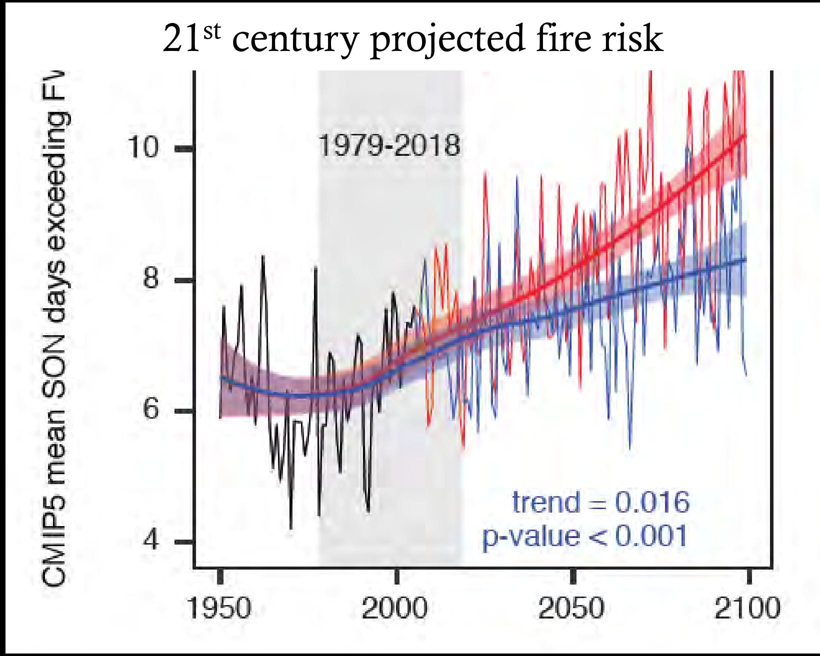
Climate change is making wildfires larger, more intense, and more dangerous





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

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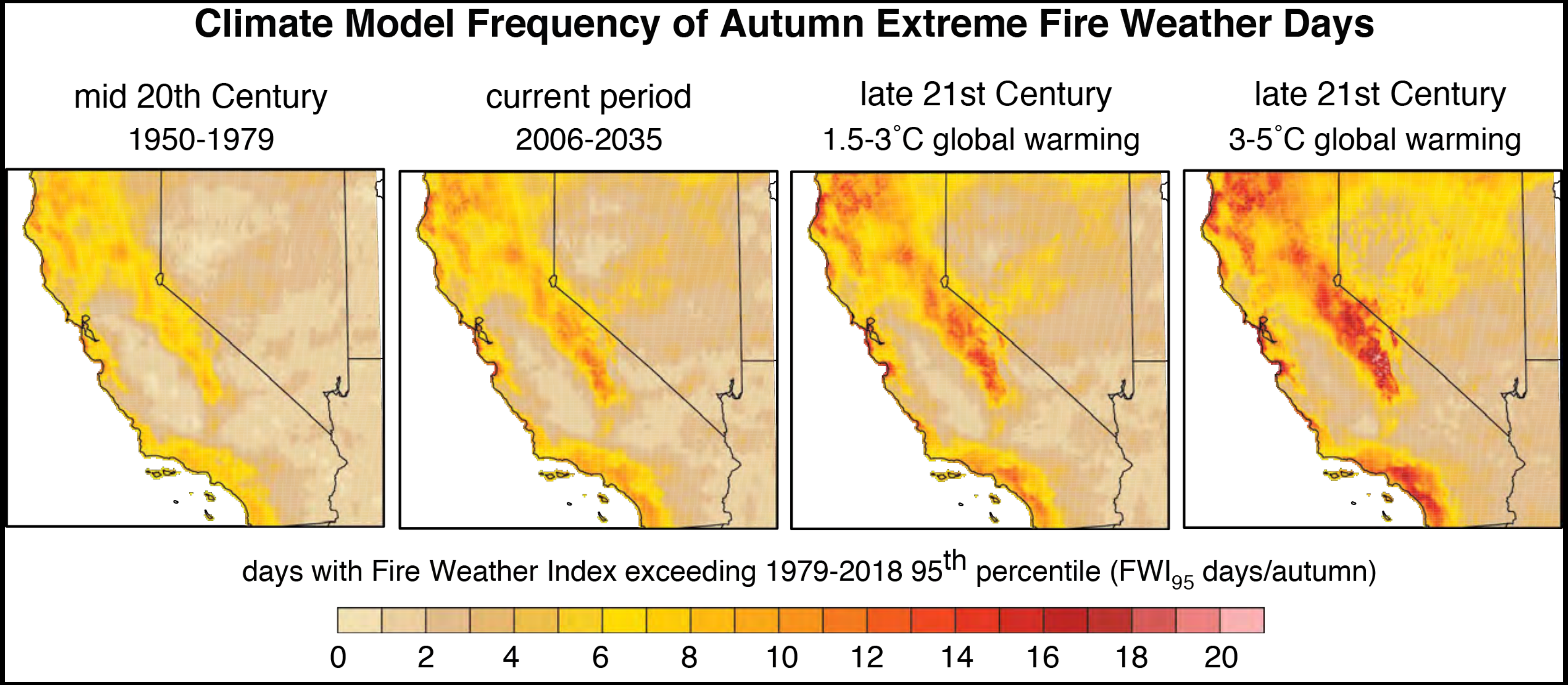
A "new abnormal" for California wildfire



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

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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?

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To cope with increasing extremes, 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
- Can we mitigate flood & drought risk simultaneously (i.e., FIRO-floodMAR), & fight (harmful) fire with (good) fire (i.e., prescribed fire)?
- It's becoming abundantly clear that historical paradigms and management practices aren't going to cut it in 21st century.

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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 flood, wildfire, and drought 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. New and innovative management strategies will be key.

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Thank you! Questions?

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