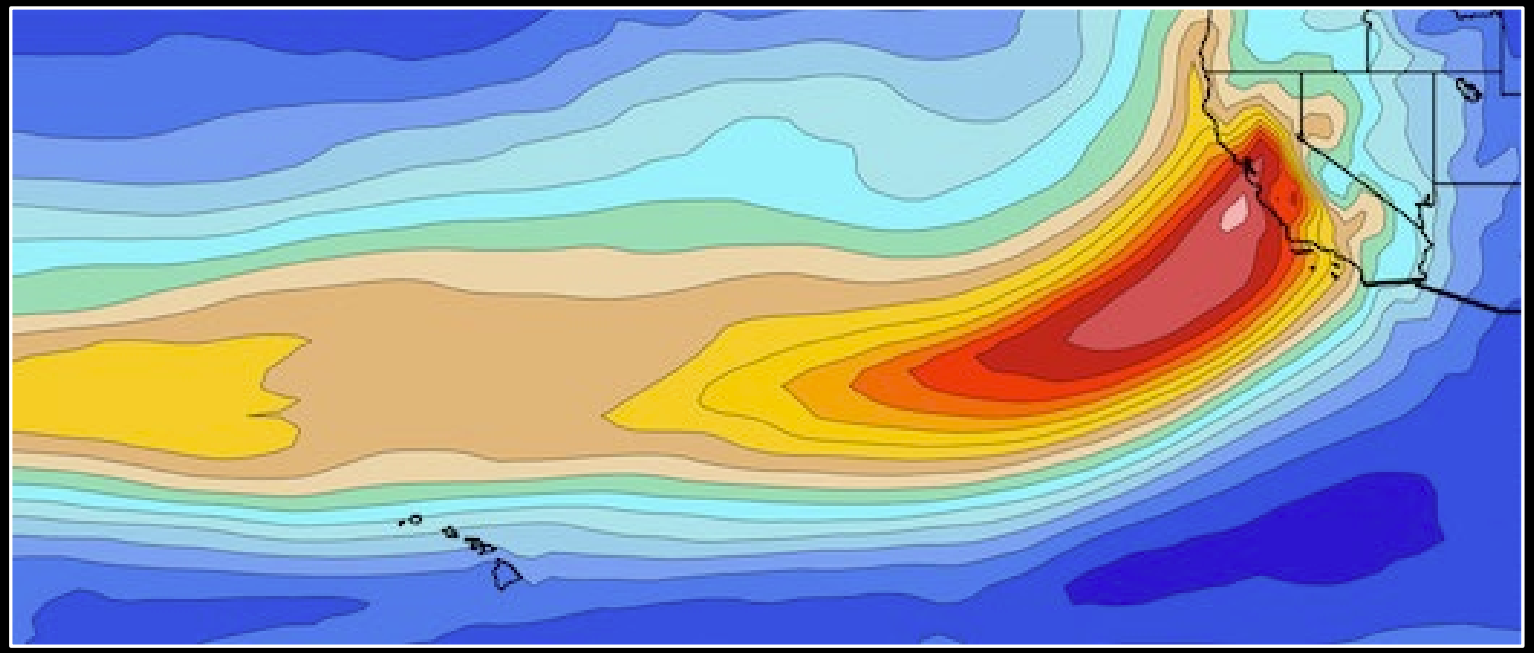
California flood risk looms large as atmospheric rivers intensify in a warming climate



Daniel Swain

UCLA, NCAR, The Nature Conservancy

CA Central Valley Flood Control Association Flood Forum

April 2023

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A hybrid role at the intersection of weather, climate, society, & environment

This presentation and related research/communication efforts were made possible by a unique partnership between UCLA, NCAR, and The Nature Conservancy.

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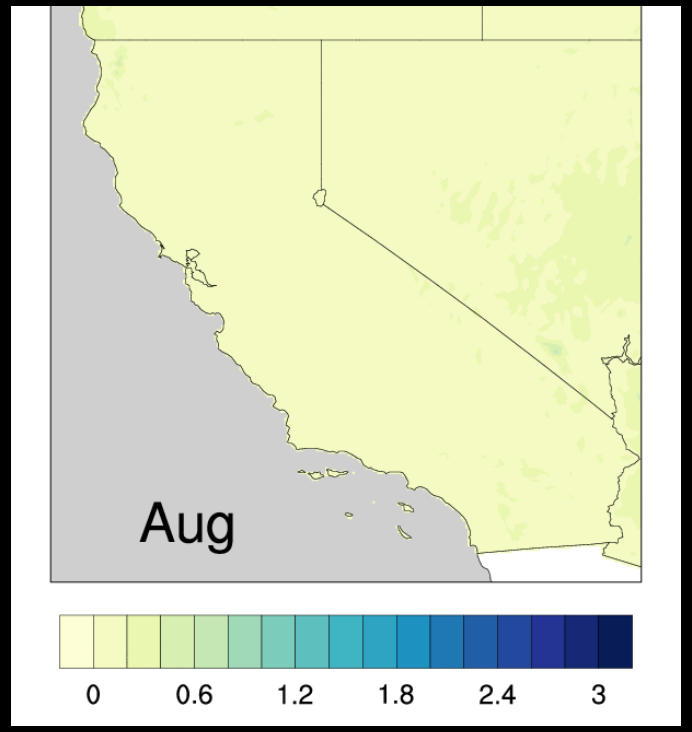
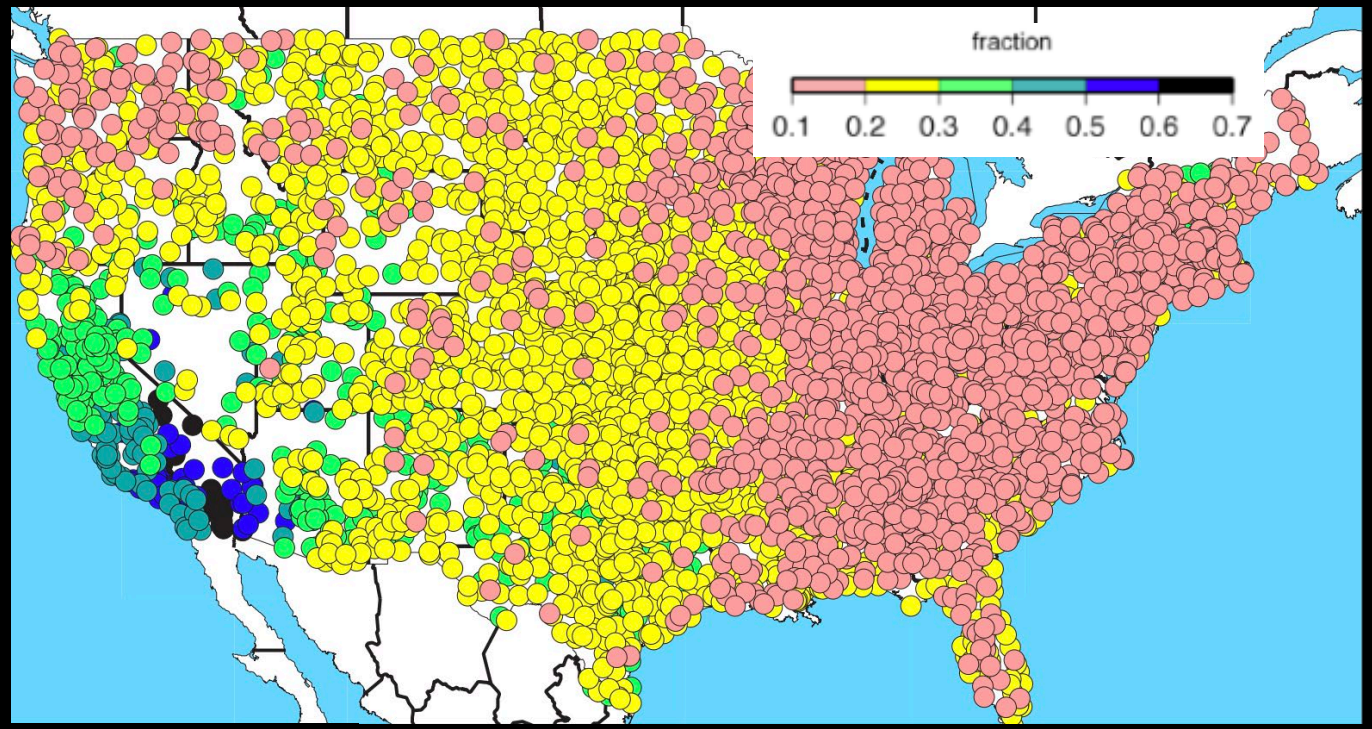
Primer: California's unusual climate context

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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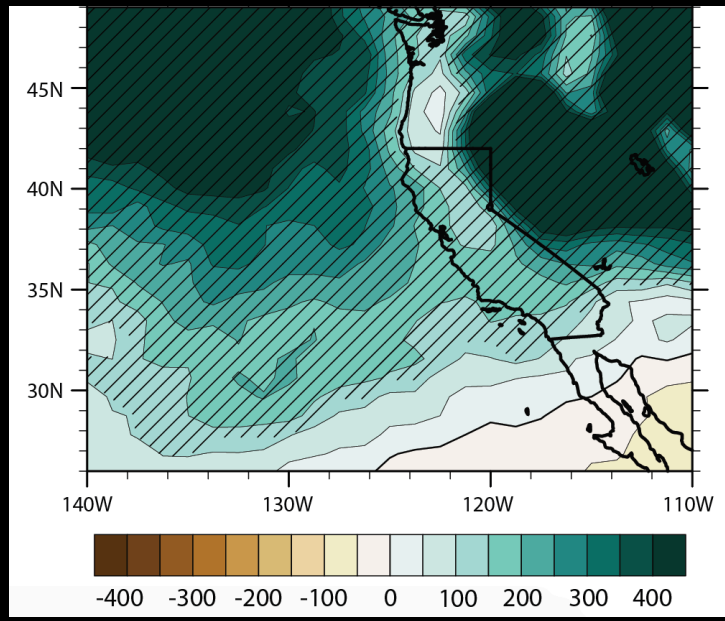
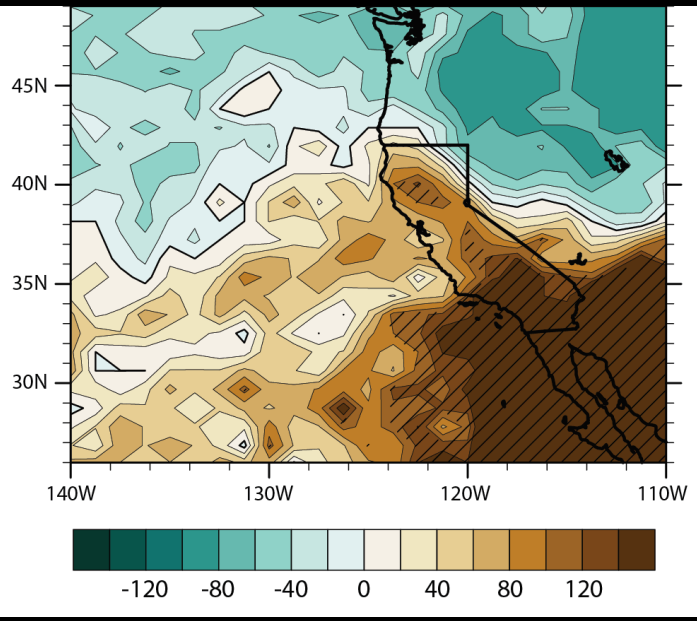
A wetter *and* drier future?

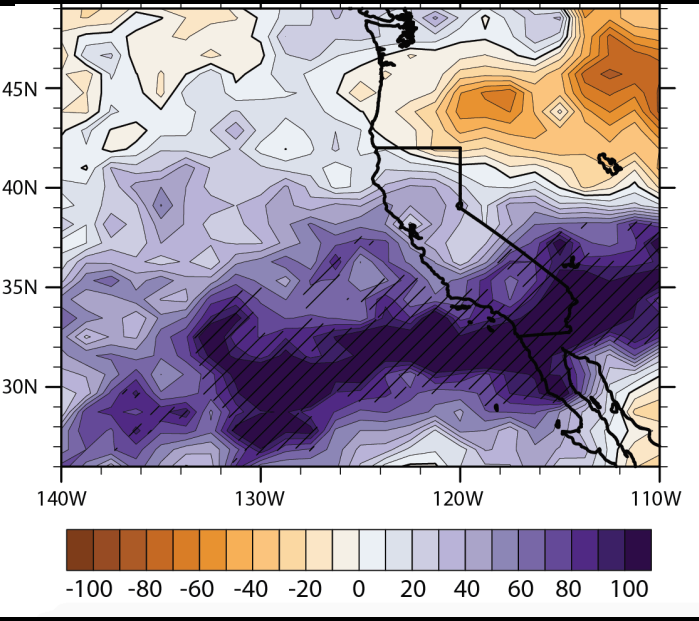
Increase in very wet years



Increase in very dry years



Increase in "whiplash"



Swain et al. 2018

Large increase in both wet & dry extremes

despite little mean precip change!

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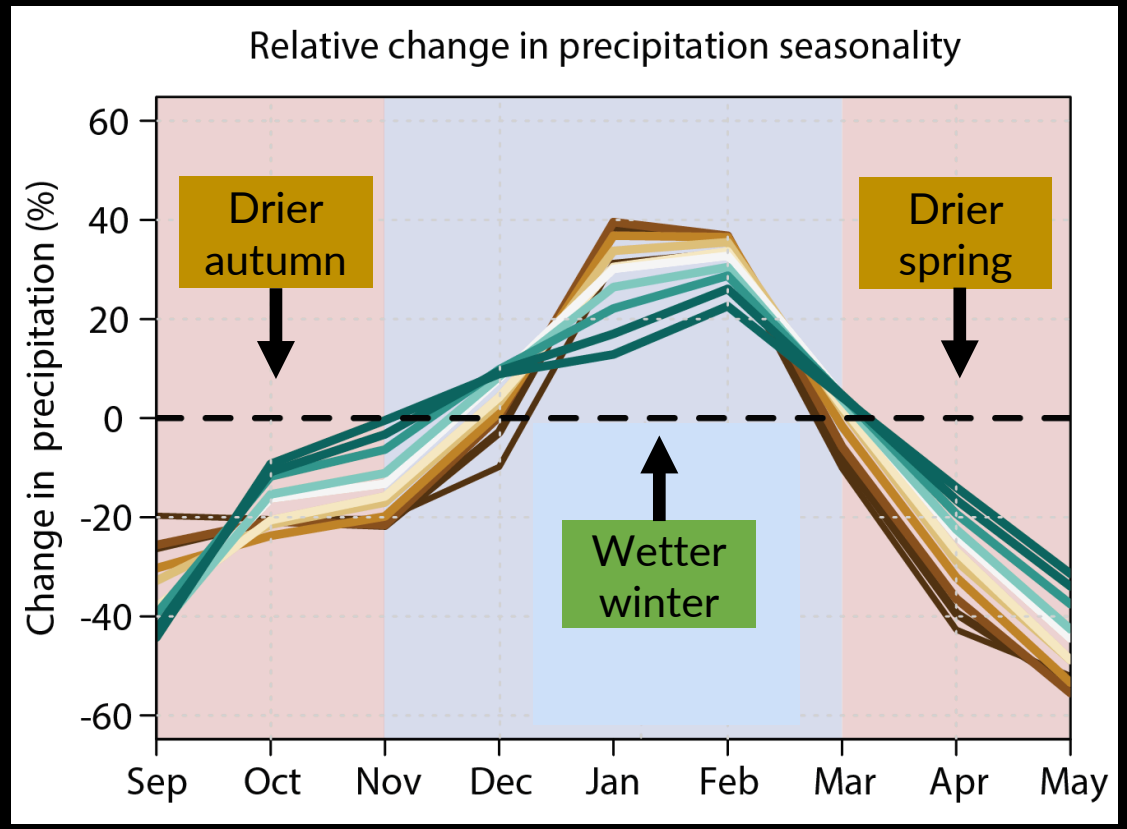
An (even) shorter, (even) sharper rainy season



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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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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What's causing this increasing hydroclimate whiplash? An expanding "atmospheric sponge"

Atmosphere ~100 years ago

Atmosphere at +2C (3.6F) of warming

- Water vapor holding capacity of atmospheric increases *exponentially*
- Increased ceiling on precipitation intensity, but also on evaporative demand
- Acceleration of hydrologic cycle and related extremes (wet *and* dry!)
- Increasing "hydroclimate whiplash" across diverse geographies

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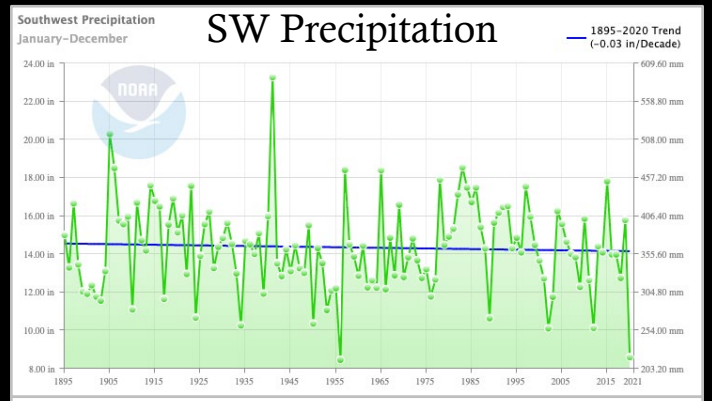
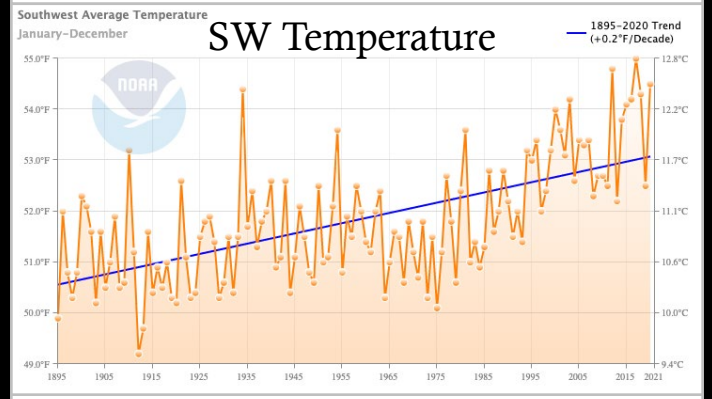
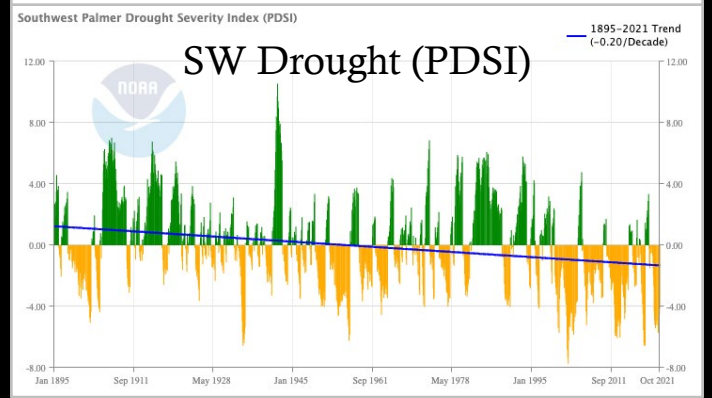
Droughts in a warming climate: Temperature emerging as a key driver







- 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
- More precipitation on fewer days, with more intense (but fewer?) storms
- Less snowpack, but stronger evaporative demand
- Droughts used to be hot or cold…but now they're all hot.

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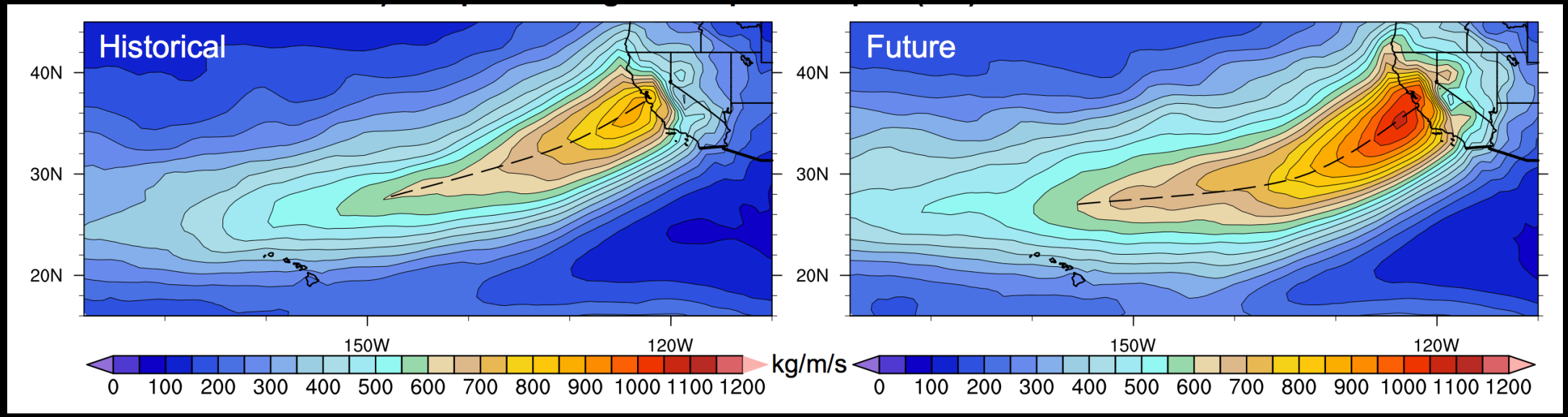
Stronger, moister atmospheric river storms

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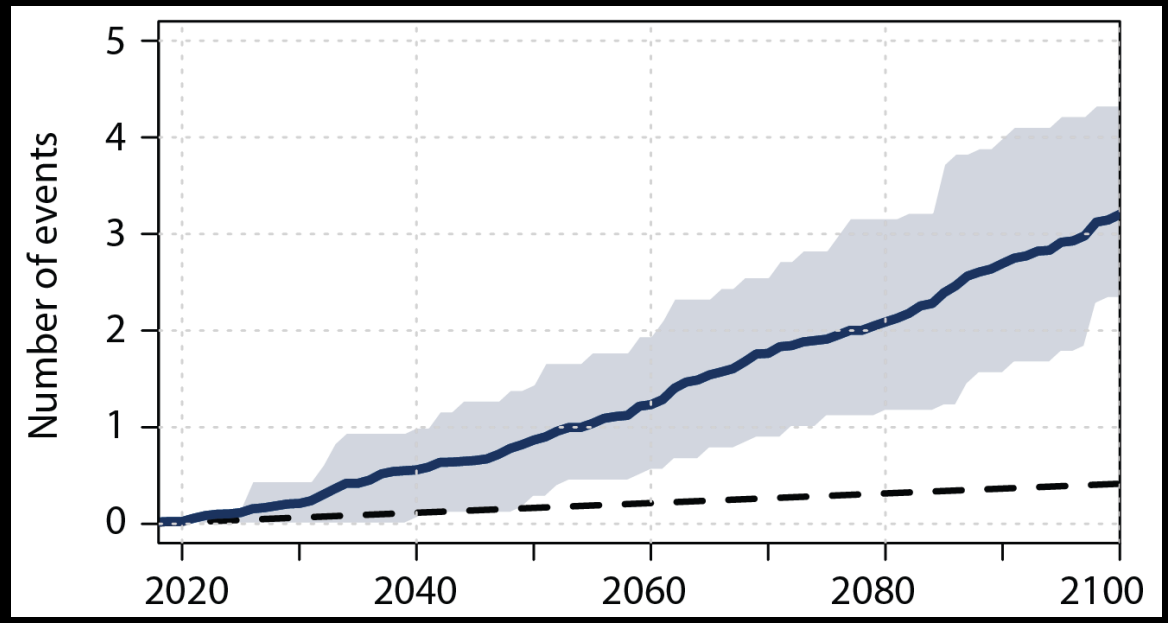
California's "Other Big One": Month-long atmospheric river deluge

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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The new ARkStorm 2.0 scenario: A weeks-long atmospheric river onslaught…

Huang and Swain 2022

- Each of the two (ARkHist and ARkFuture) scenarios involve a 3-4 week long sequence of atmospheric river storms affecting CA

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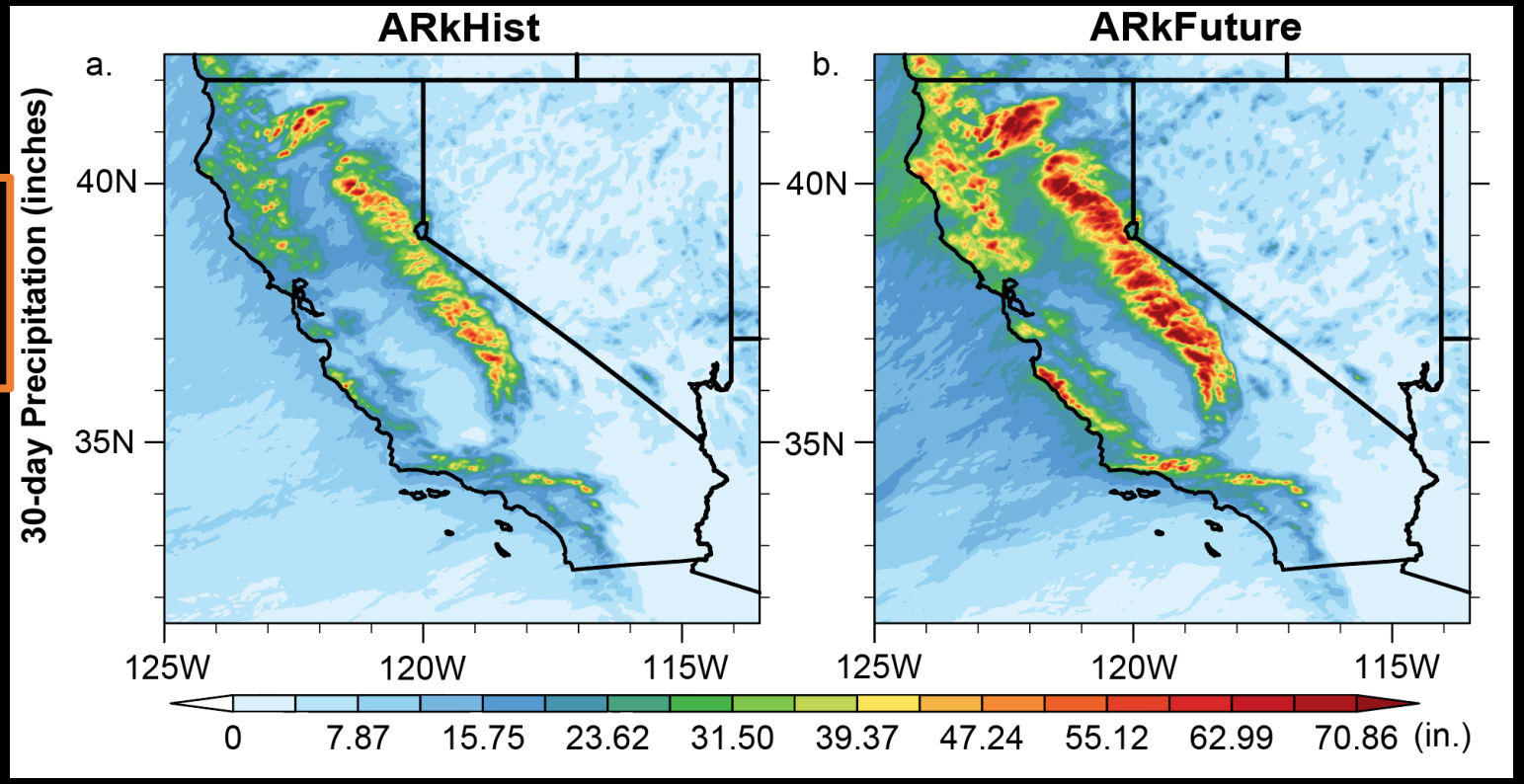
Feet of rain in California's mountains

Total accumulated 30-day precipitation, ARkHist vs. ARkFuture scenarios

Dec-Jan 2022-2023 event
= ~ 80% of ARkHist
= ~50% of ARkFuture



Huang and Swain 2022

- A 3-4 week long sequence of strong and moist atmospheric river storms would deliver *feet* of rain to most of California over a 30 day period—locally 80-100+ inches of water in the mountains.

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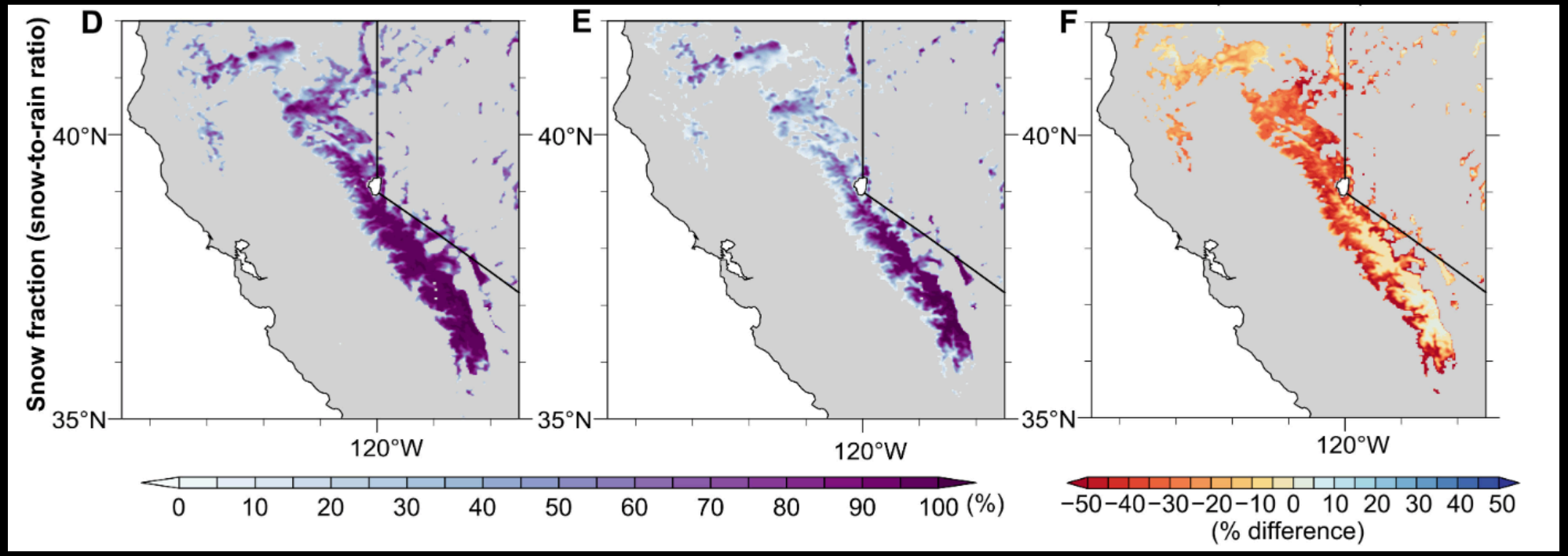
In warming climate, more rain than snow

Change in snow fraction, ARkHist (left) vs. ARkFuture (center) scenarios



Huang and Swain 2022

- Dramatic shift toward rain in CA's mountains except at highest elevations
- Major implications for immediate surface runoff

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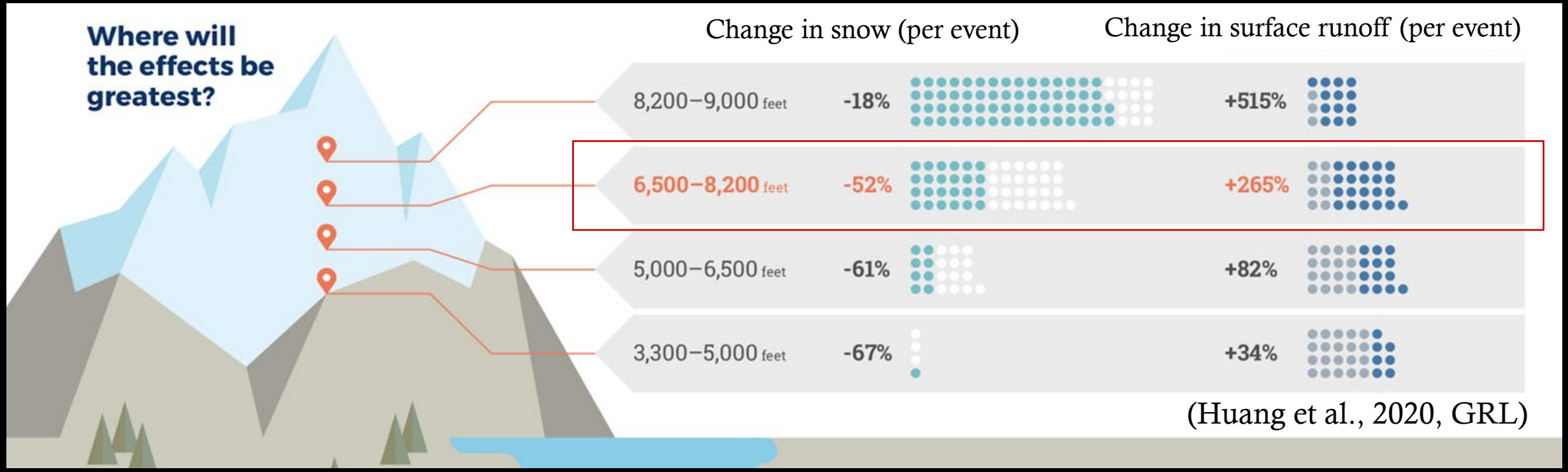
“Double Whammy Effect” in the Sierra Nevada

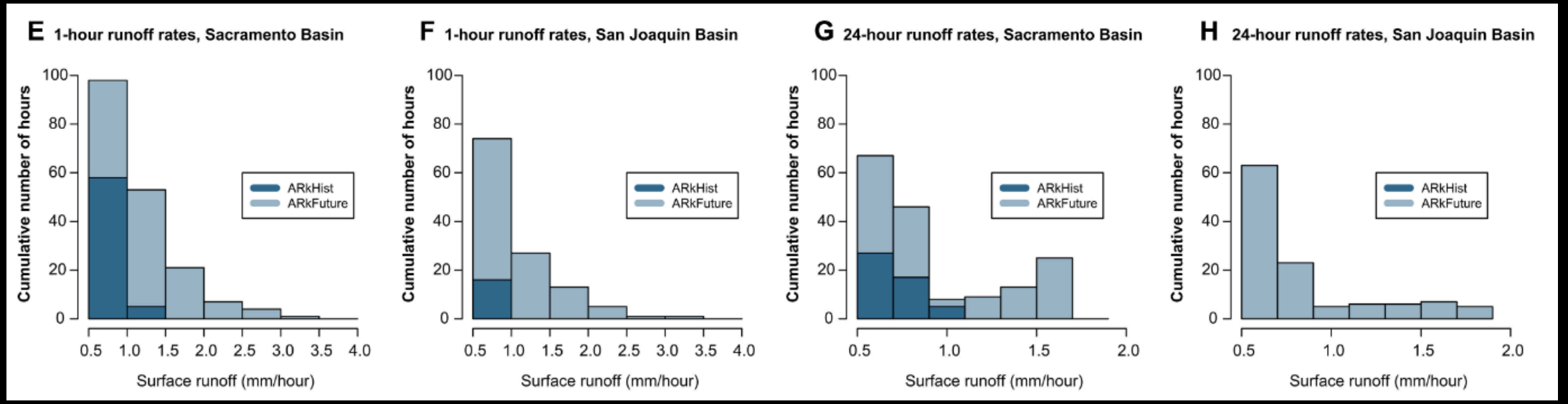


(Huang et al., 2020, GRL)

- “Double whammy” effect arises from:
  - 1) Increase in precip intensity/cumulative storm totals
  - 2) Phase change from rain to snow
- Net effect: extremely large increases in upper-tail runoff peaks
- Large increases in flood risk, and also loss of snowpack H20 storage

In warming climate, much higher runoff

Upper tail of surface runoff histogram, ARkHist and ARkFuture



Huang and Swain 2022

- Runoff increases strongly everywhere, but especially in mountain areas that switch from snow to rain
- Extremely large increases (300-400%) in peak runoff within San Joaquin/Southern Sierra watersheds. Essentially a novel regime.

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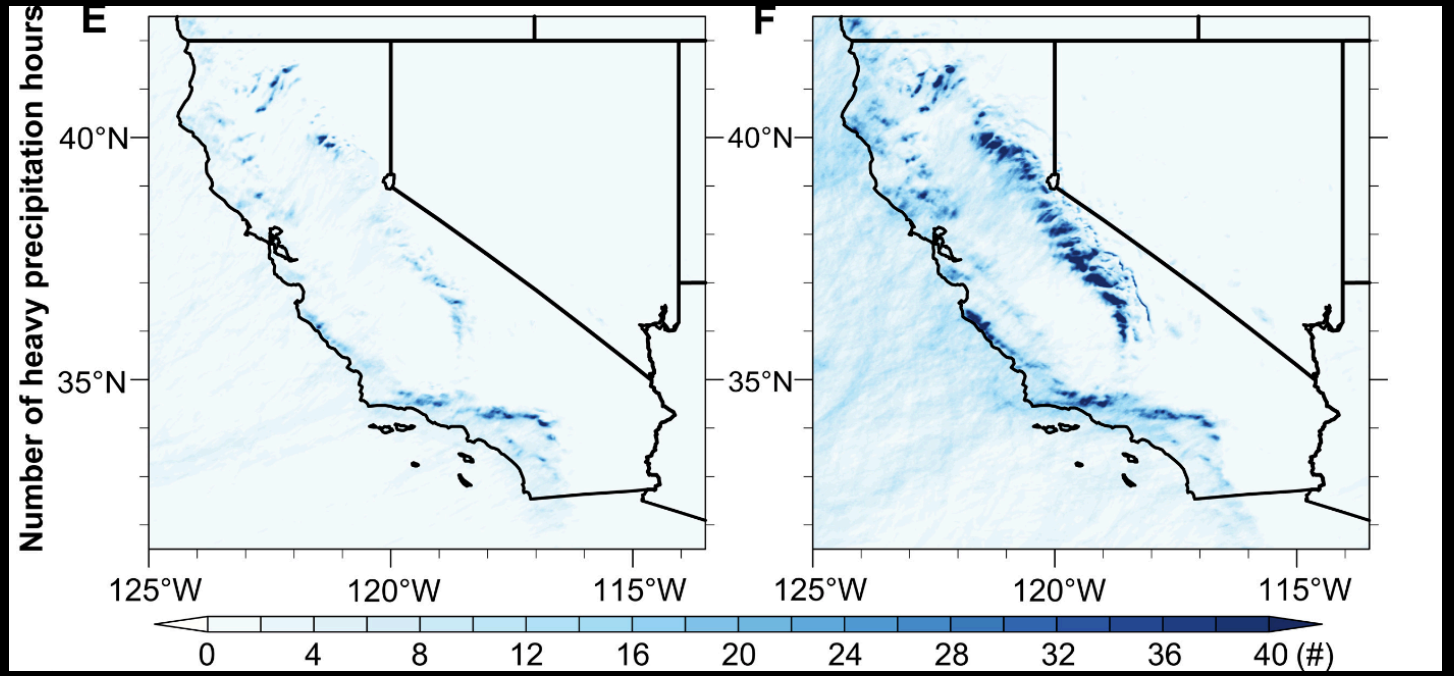
A note about flash flood and debris flow risk

Change in the nmber of heavy precip hours, ARkHist (left) & ARkFuture (right)



Huang and Swain 2022

- In this and previous work, we find particularly large increases in hourly rainfall intensities with climate warming
- Associated concerns: large increases in flash flood, urban flood, & debris flow risks (especially in/near recent wildfire burn areas)

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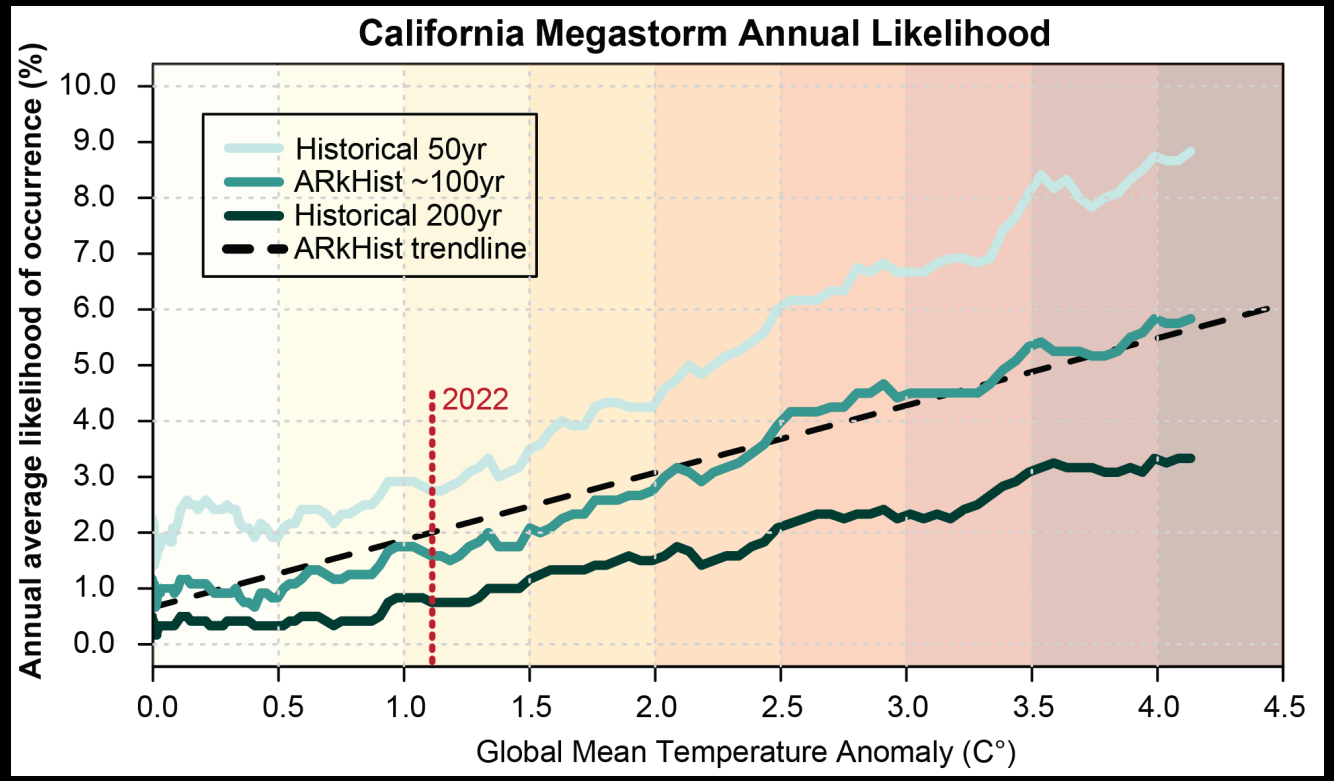
Climate change is increasing the risk of a California megastorm



Huang and Swain 2022

- Climate change between ~1920 and ~2020 has doubled the likelihood of a California megaflood
- Cumulative risk of ARkHist level event between 2020-2060? >65%!

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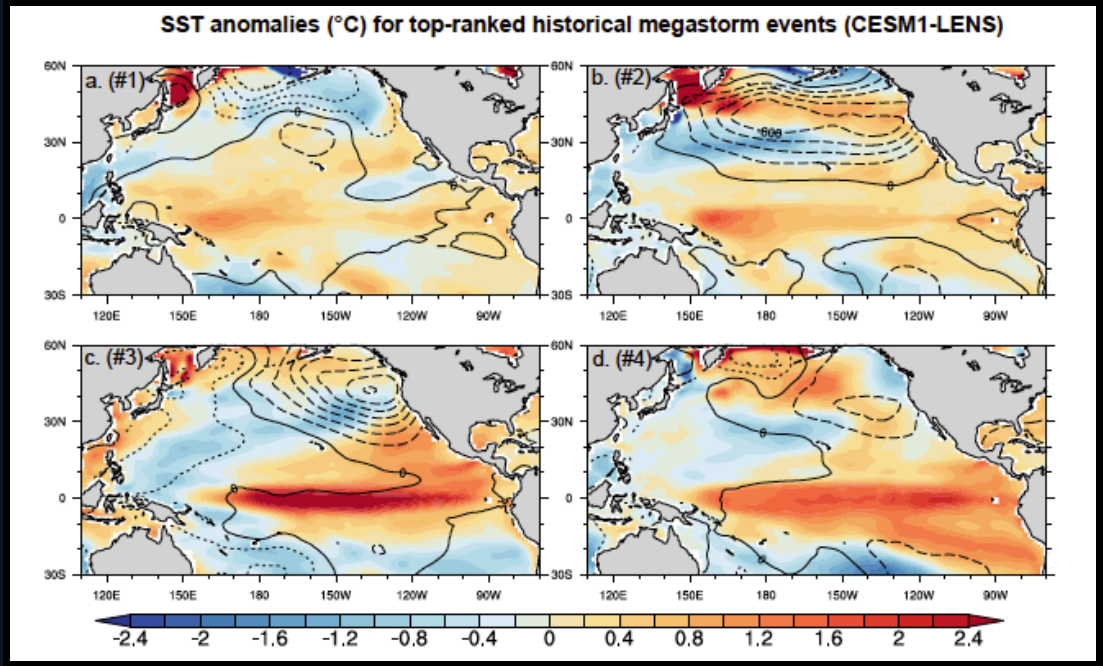
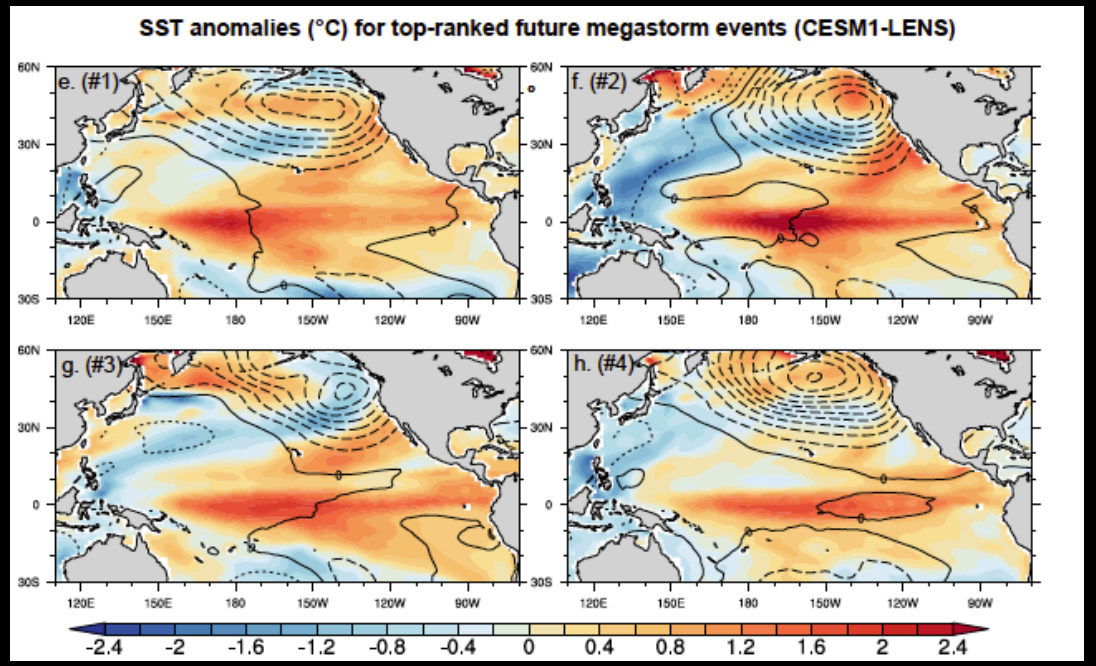
Might California megafloods have seasonal-scale predictability?





Huang and Swain 2022

- All 8 projected top "megaflood" candidates in CESM-LENS occur during El Niño conditions (7 of 8 moderate to strong)
- We can predict ENSO 3-6+ months in advance. Might there be seasonal-scale predictability of megaflood risk?

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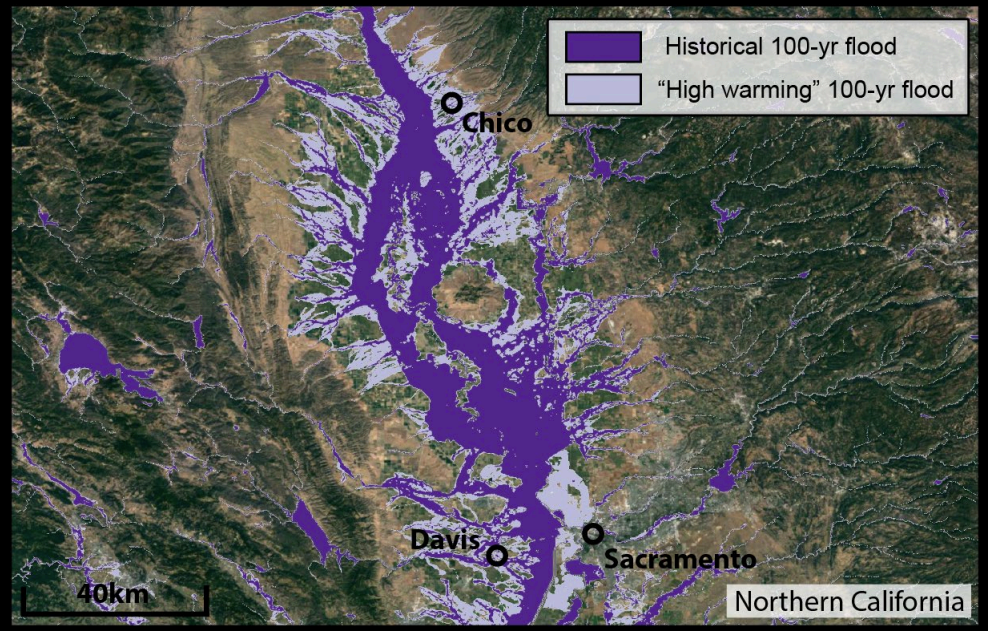
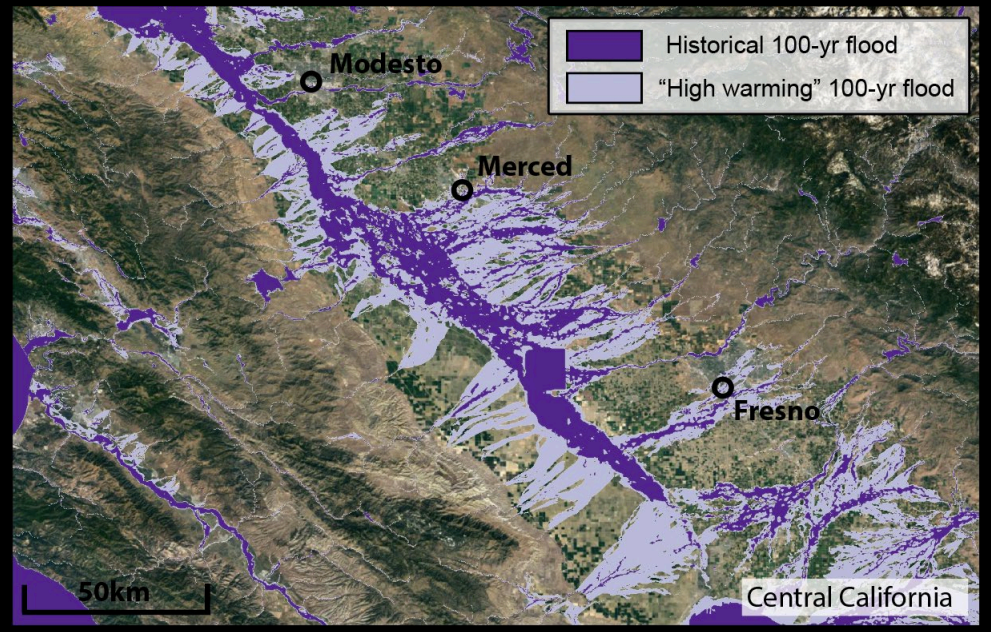
California flood risk looms large in warming climate

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 flash flooding & debris flows?
  - Flood protection structural problems: low probability/high consequence events

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A modern megaflood would be an unprecedented California disaster

- A megaflood would be California's "Other Big One"
- No modern precedent for an 1862-like great flood
- California's water & flood protection built for a 20th century climate that no longer exists. How would it fare?
- Phases II and III of ARkStorm 2.0 will provide more quantitative assessments, but…
- ARkStorm 1.0: ~$1 trillion in overall losses (2022 dollars)
- Millions displaced for weeks or longer
- Most transportation corridors damaged or destroyed
- Nearly all economic sectors affected simultaneously

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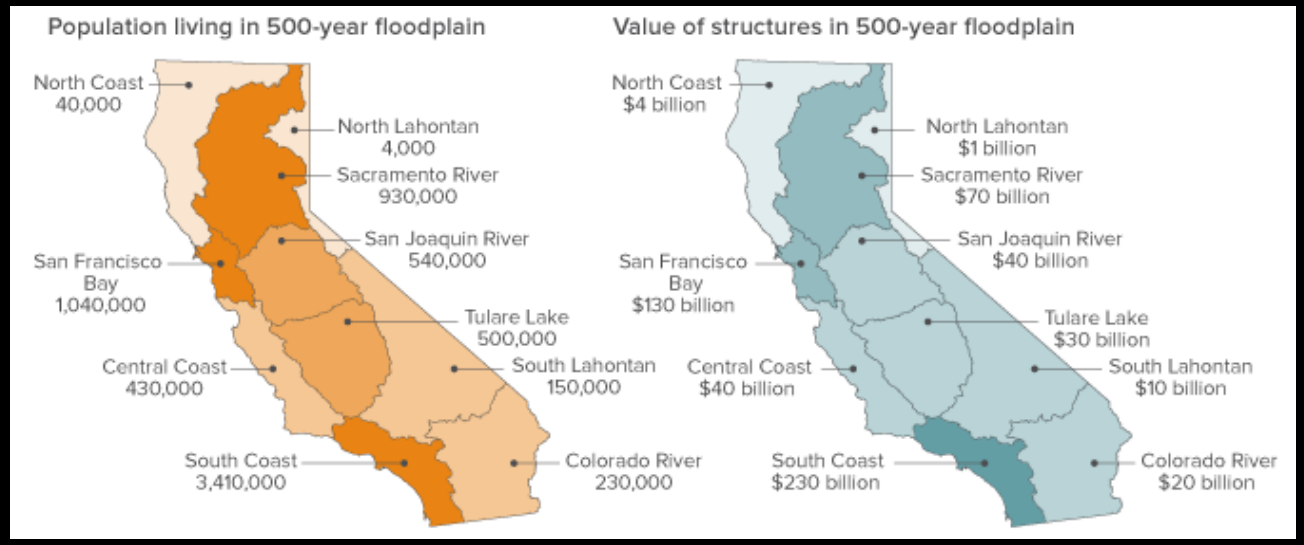
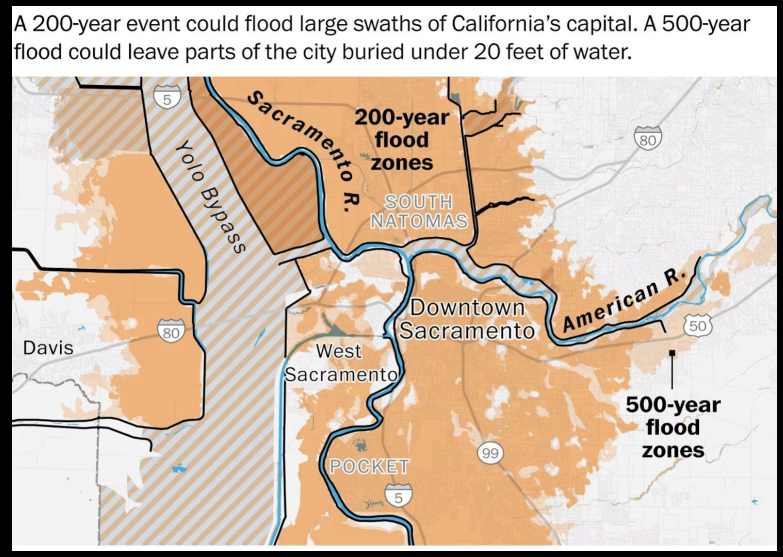
A grand challenge for policymakers, decision-makers, and engineers

Estimated flood risk in California



Public Policy Institute of California

"200 year" flood map for Sacramento



Washington Post

- Existing infrastructure is "under-engineered" for future climate
- Increasing "precipitation whiplash" = more challenging water management
- Tension between competing flood control & drought mitigation mandates will become even more pronounced

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To cope with increasing extremes, flexible adaptations will be key

Yolo Bypass (in flood) near Sacramento

- Physical reality: increase in both precip intensity *and* overall aridity, dramatic loss of snowpack, more intense runoff.
- Can we mitigate flood & drought risk simultaneously?
- It's becoming abundantly clear that historical paradigms and management practices aren't going to cut it in 21st century.

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How to adapt to rising risk?

Yolo Bypass near
West Sacramento

- Ensuring "hard" infrastructure—levees, dams & auxiliary structures, urban flood conduits—will perform as expected. Critically re-assess levels of protection, and consider "plausible worst case" scenarios.
- Greatly expanding "soft" infrastructure: levee setbacks, river bypasses, floodplain restoration
- FIRO (flood-informed reservoir operations) and MAR (managed aquifer recharge). Expand flood pools by shifting underground?
- Improve public & agency awareness of risks; tabletop disaster response exercises; improved data visualization and dissemination

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How do we honestly, but thoughtfully, talk about catastrophic flood risk?

- Genuinely catastrophic, widespread flood events *already possible* in California's historical climate. 20th century does not provide a good enough guide re: high magnitude events that are plausible in CA.
- Reliable, well-operated, and flexible flood control infrastructure *helps greatly during most floods*. Let's make sure these systems are in as good of shape as they can be! Lots of work still to be done here.
- But in a sufficiently extreme scenario (including ones we believe are highly plausible in coming decades), the water will win.
- How can we constructively plan for "The Big One?"
- Focus shifts from damage mitigation to life protection. How to do so at scale? And what about long-term recovery?

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Closing thoughts

- A modern California megaflood would be unprecedented disaster, substantially different in character to earthquake or wildfire
- Much larger storm sequences (and floods) than were observed in 20th century (& 2022-2023) are highly plausible.
- Climate change has already doubled odds of an extremely severe storm sequence capable of producing catastrophic flooding
- Increasing hydroclimate whiplash: flood risk looms large
- ARkStorm 2.0 project exploring broader implications; stay tuned for further results
- Much can be done to mitigate risks: hard and soft infrastructure improvement; flexible and dynamic water/flood management
- Flood and water managers will be on front lines in a warming CA

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Thank you! Questions?

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