Climate Projections for California:
What We Knew Then (1989), What We Know Now (2019)

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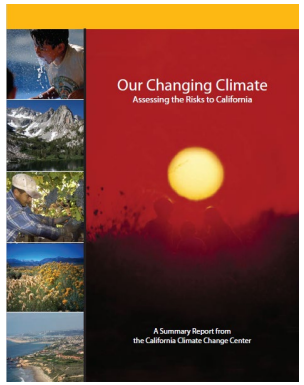
Outline

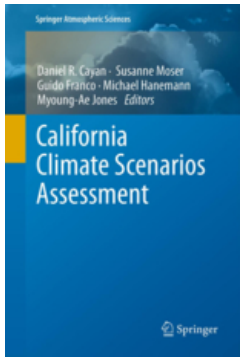
- **What did we expect in 1989?**
  - Decreased snowpack, greater winter streamflows, lesser summer flows.
  - Today's observations and sophisticated projections generally concur.
- **Rising atmospheric CO_2:** 21st century observations and paleo record
- **Projections have also illuminated:**
  - A "drier" state is expected in terms of soil moisture, even as mean statewide precipitation remains uncertain.
  - Timing of precipitation expected to exacerbate drought-related risks.
  - Distribution of precipitation reveals regional differences: wetter north, drier south.
  - Extremes are expected to become more pronounced, with greater variability of precipitation.
- **Effect of climate change on fog** merits further inquiry

Climate change and impacts to California: 30+ years of vulnerability assessments

June 1989

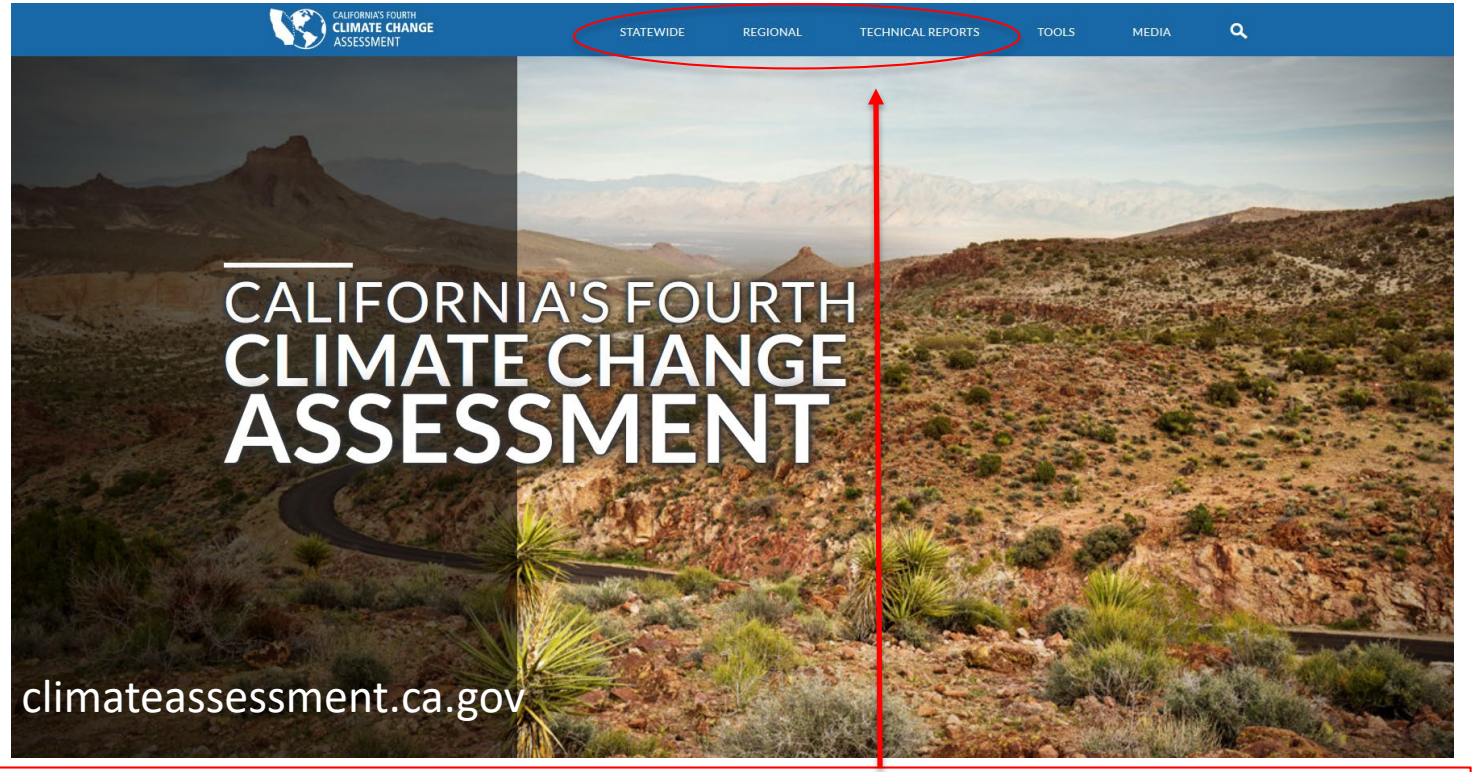


First Assessment
2006



Second Assessment
2009

Third Assessment
2012

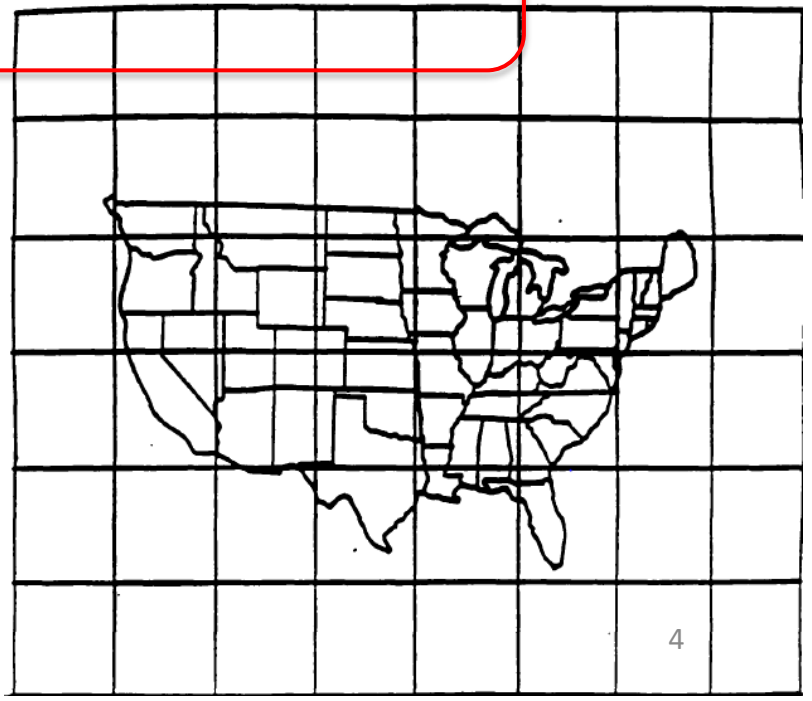


Includes 44 peer-reviewed **technical reports** plus 9 **regional reports** to synthesize and contextualize findings for regional audiences. Plus a **statewide integration report,** as well as synthesis reports on ocean & coast, tribal & indigenous communities, and climate justice.

What was known in 1989 regarding climate change impacts to California?

"The Committee found the state is at risk from the following impacts:"

- Water Resources ("Significant Risk")
  - "No clear indication" whether total statewide precipitation will increase or decrease.
  - "Likely" that warming-induced decrease in snowpack storage will increase winter stream flows and flooding and decrease summer flows.
- Other sectors and resources identified as "at risk":
  - Forestry, rising ocean level, natural habitat, regional air quality, and human health-- "Significant Risk"
  - Electrical energy, the California economy-- "Moderate Risk"
  - Agriculture-- "No Clear Risk"



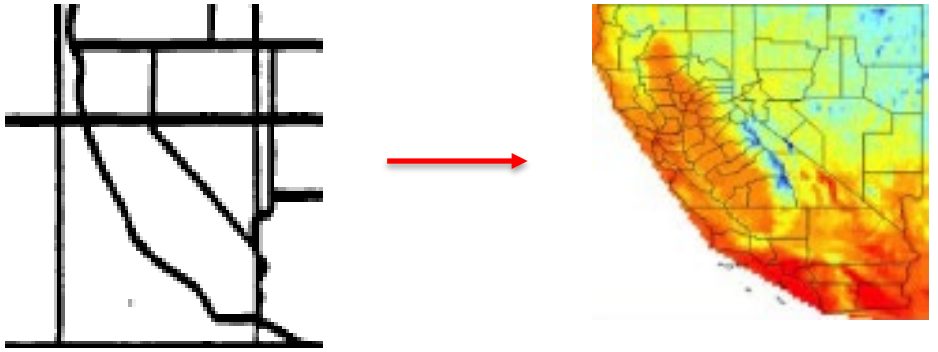
Atmospheric models available in the late 1980's were too coarse to resolve California-specific impacts. For example, in 1988, the Goddard Institute for Space Studies' (GISS) state-of-the-art model represents most of California and half of Nevada in a single grid cell. (From p. 10, *The Impacts of Global Warming on California*, 1989.)

What is known in 2019 regarding climate change impacts to California?

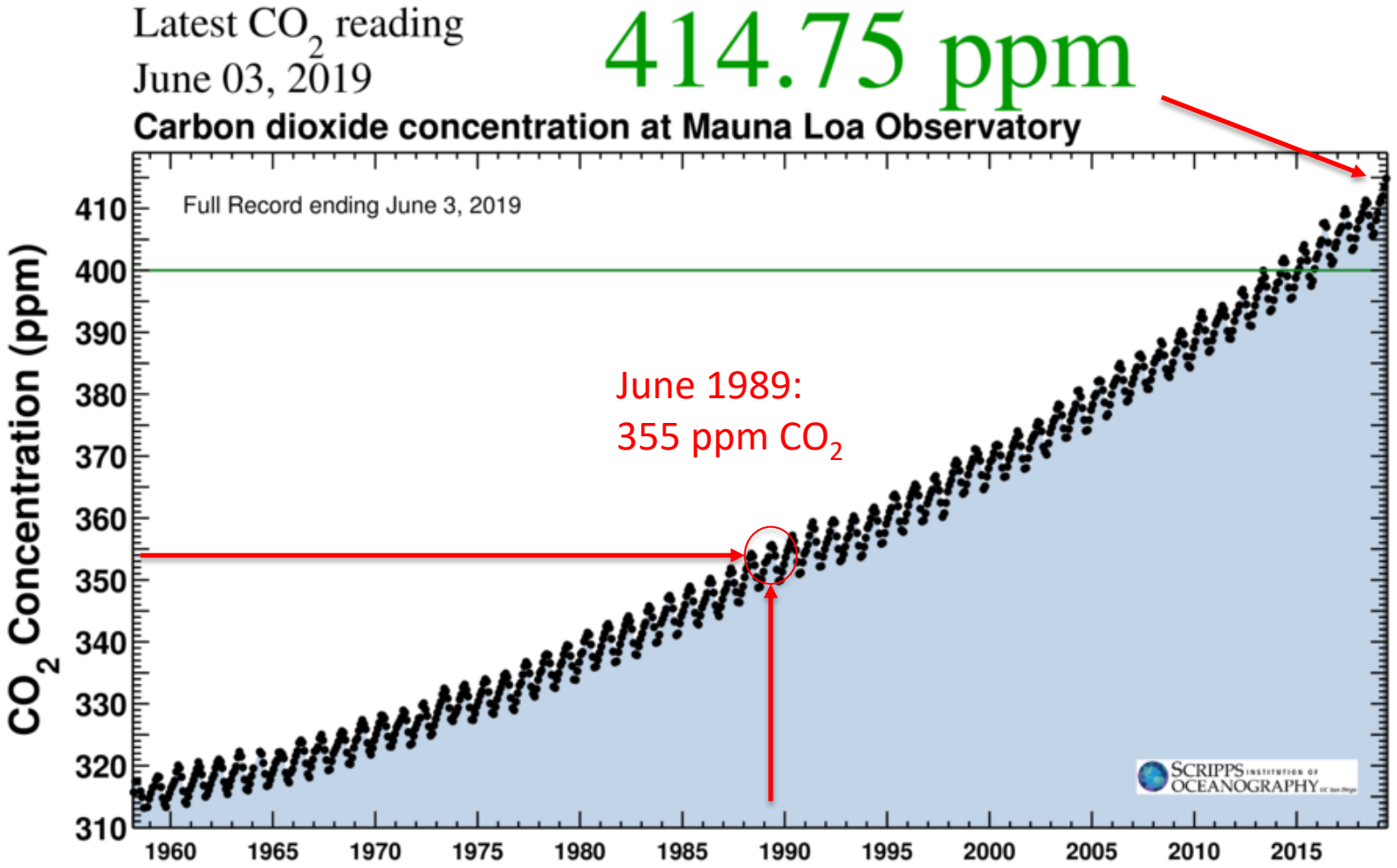
What have we learned since 1989, given:

- Thirty years of atmospheric observations
- Extended geological record
- Observational data and analysis of trends in California
- Projections developed to support California's Fourth Climate Change Assessment

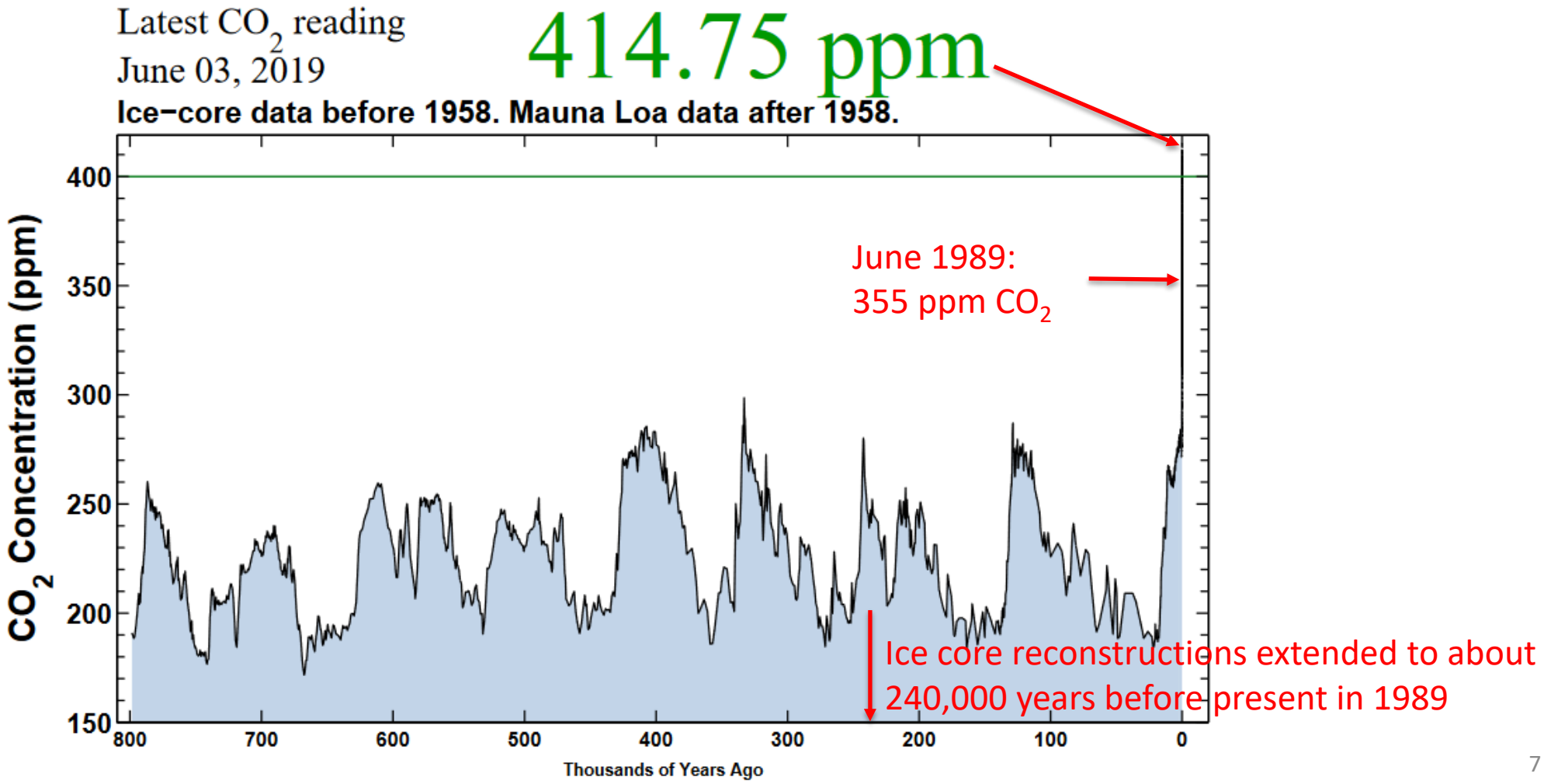
Whereas the coarse grid cells of the Goddard Institute for Space Studies' (GISS) state-of-the-art model in 1988 were not able to resolve regional climate change in California, downscaled projections developed for the Fourth Assessment are 1/16° resolution (ca. 6 km × 6 km).



Observational record: 1989 vs. 2019



Extended observational record



California's snowpack is expected to continue to decline

- Expected to decline by more than 1/3 below historical average by mid-century.
- Western U.S. has experienced a measurable reduction in April 1 SWE of since the 1950's (Mote at al. 2018).

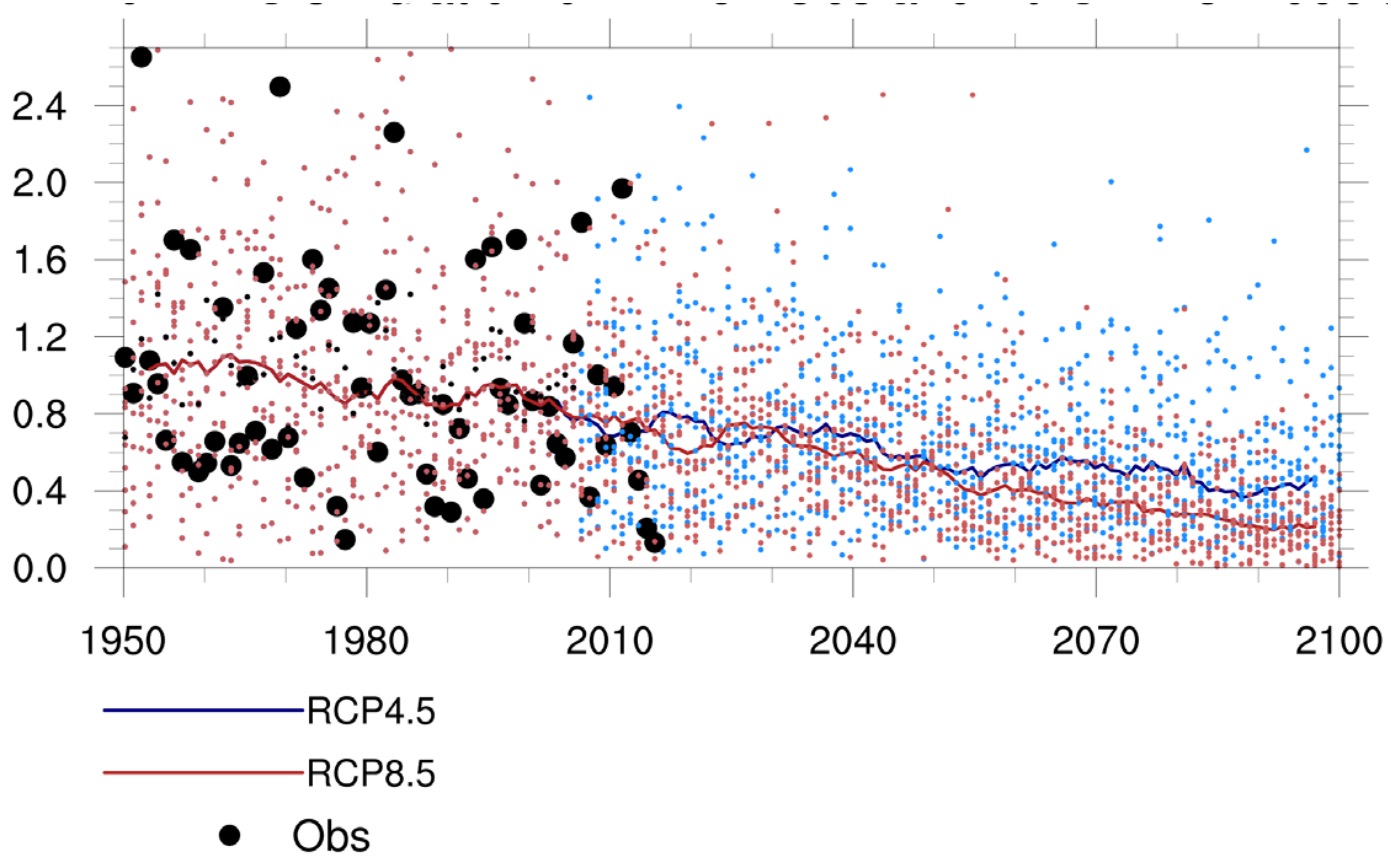
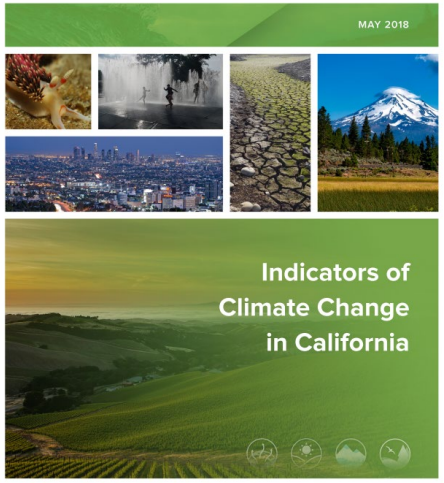


Figure: observed and projected Snow Water Equivalent (SWE) aggregated over Sierra Nevada and other catchments, shown as fraction of 1965-2000 SWE.

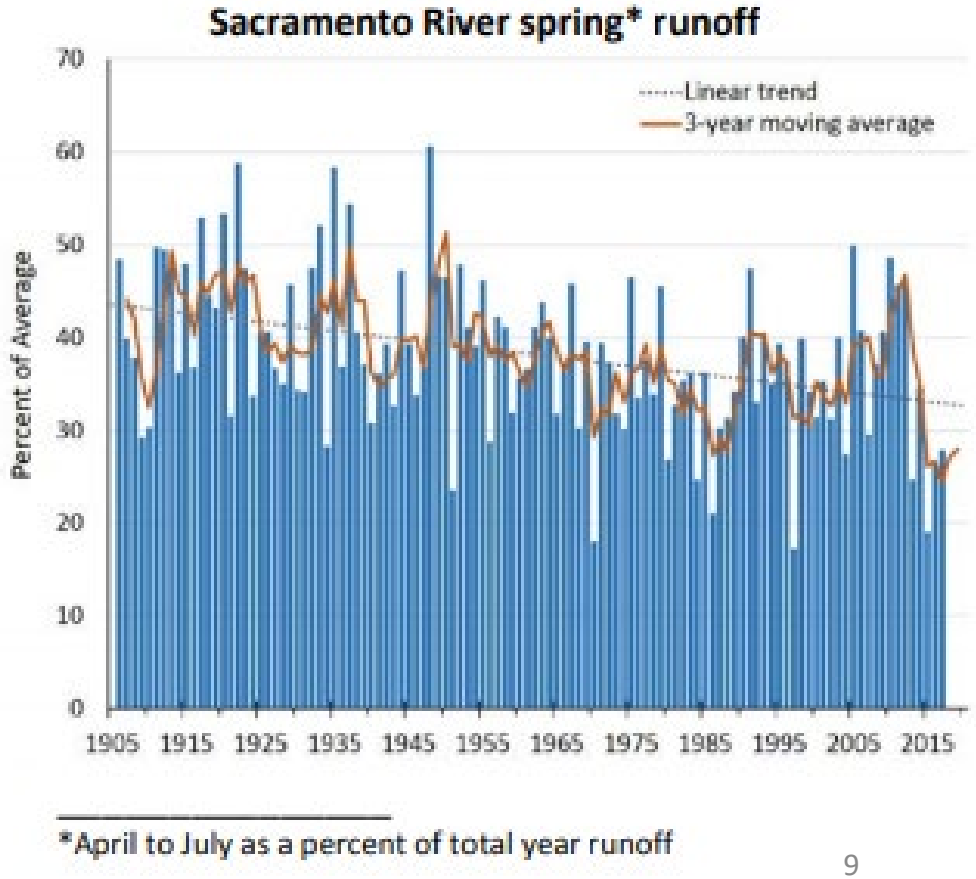
Source: Bedsworth, L., D. Cayan, G. Franco, L. Fisher, Sonya Ziaja (2018). *Statewide Summary Report*. California's Fourth Climate Change Assessment.

Climate change is already affecting streamflows in ways anticipated in 1989

- **Reduced spring runoff**: Snowmelt runoff reaching the Sacramento River between April and July has decreased by about 9% since 1906.
- Earlier spring warming, more winter precipitation falling as rain.

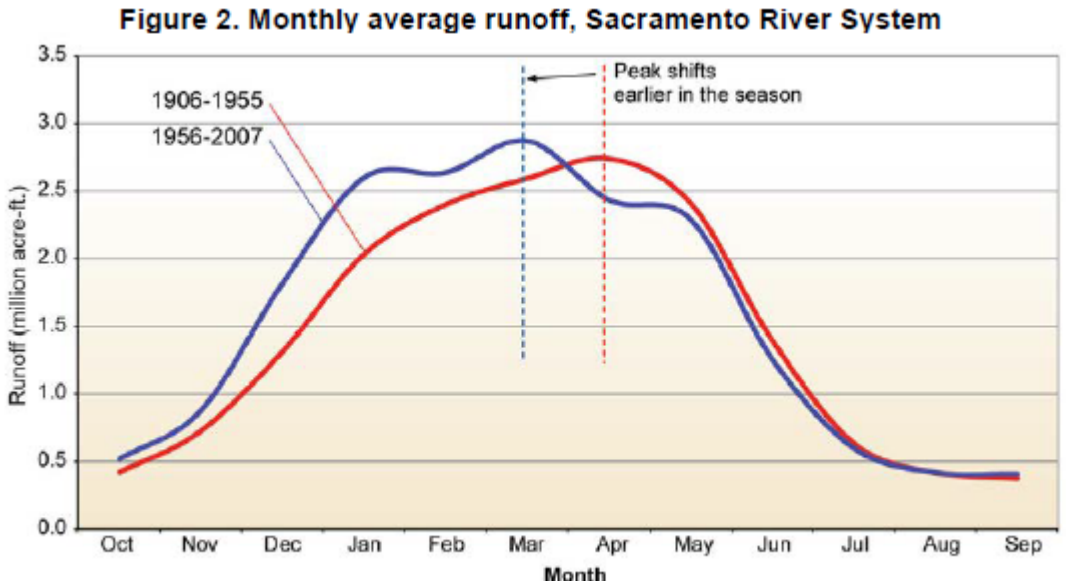


Source: *Indicators of Climate Change in California*, OEHHA, 2018.

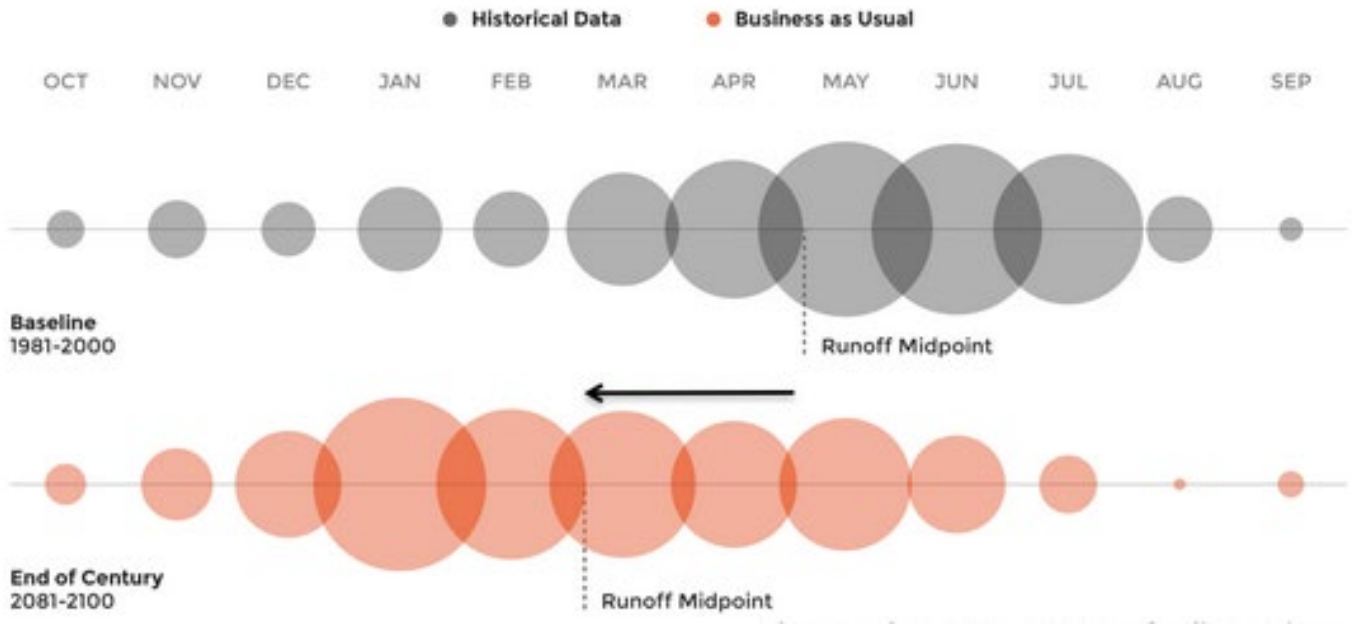


Shift in timing of streamflow toward winter peaks, as expected in 1989

- **Increased winter runoff**: observed in Sacramento River system (left).
- **Substantial, earlier shift in runoff timing** projected (right) by end-century.



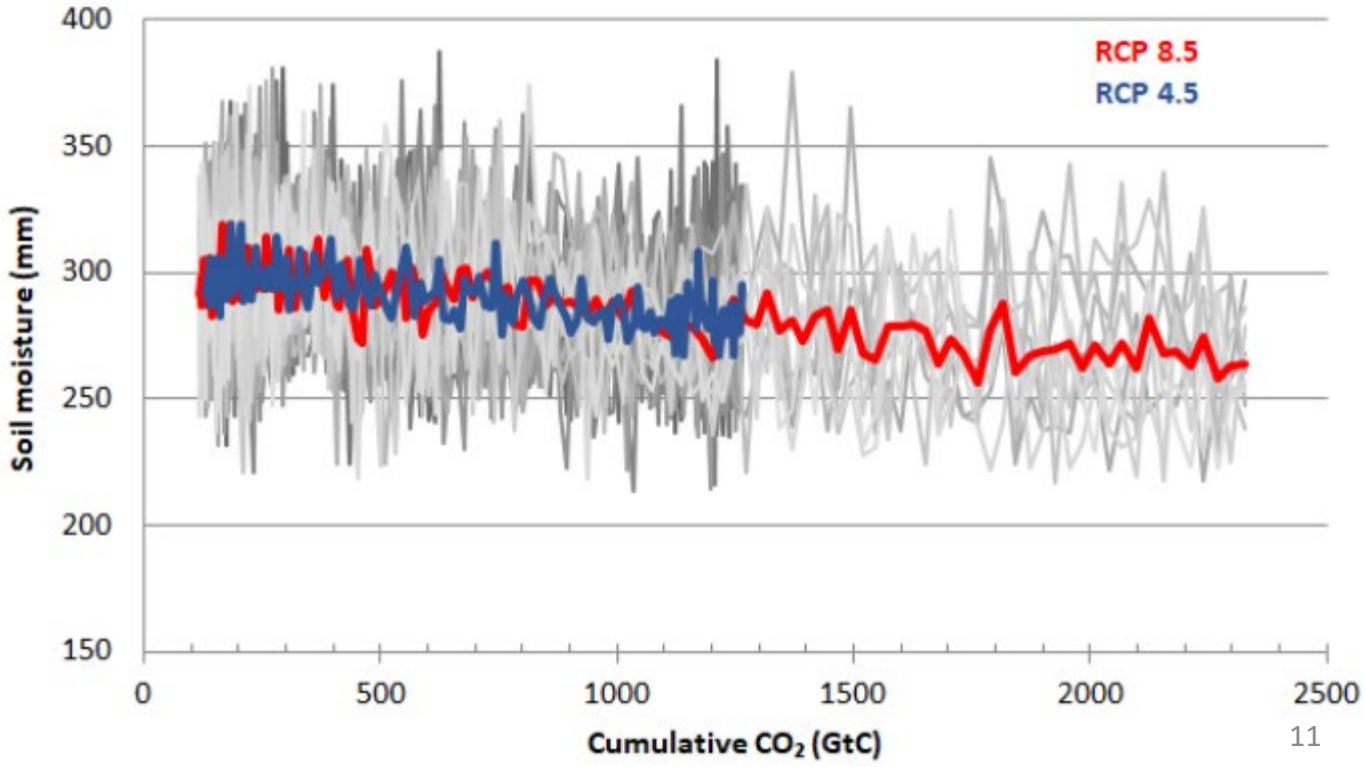
Source: DWR (2015) *California Climate Science and Data for Water Resources Management.* As featured in OEHHA (2018).



Source: Schwartz et al (2017): UCLA IoES Center for Climate Science. *See also*: Schwartz, M. and A. Hall (2017), "Significant and Inevitable End-of-Twenty-First-Century Advances in Surface Runoff Timing in California's Sierra Nevada", *Journal of Hydrometeorology*.

Expect a "drier" state, even as trend in mean statewide precipitation remains uncertain

- Inconclusive whether the state will get more or less precipitation on average.
- Average soil moisture in California is projected to decrease under climate change.
  - Up to an 11% decrease in 2070-2099 under RCP8.5
  - Could be limited to a 1.3% to 2.5% decrease if we meet 1.5°C or 2°C climate stabilization goals.

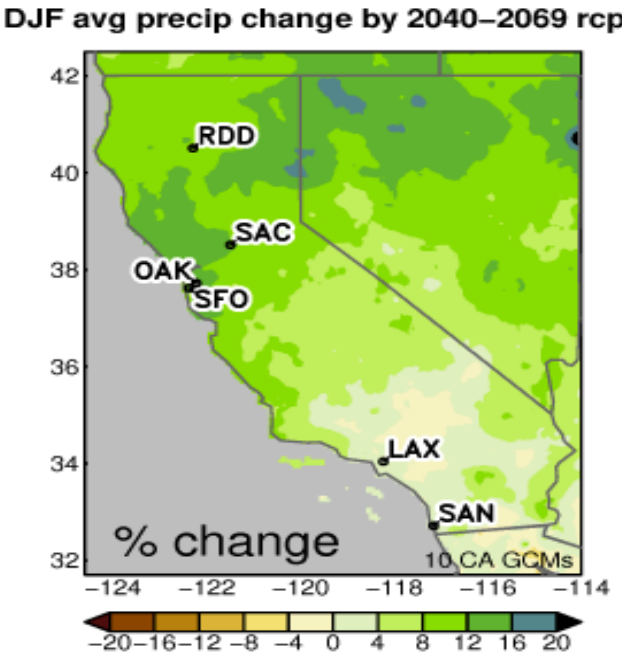


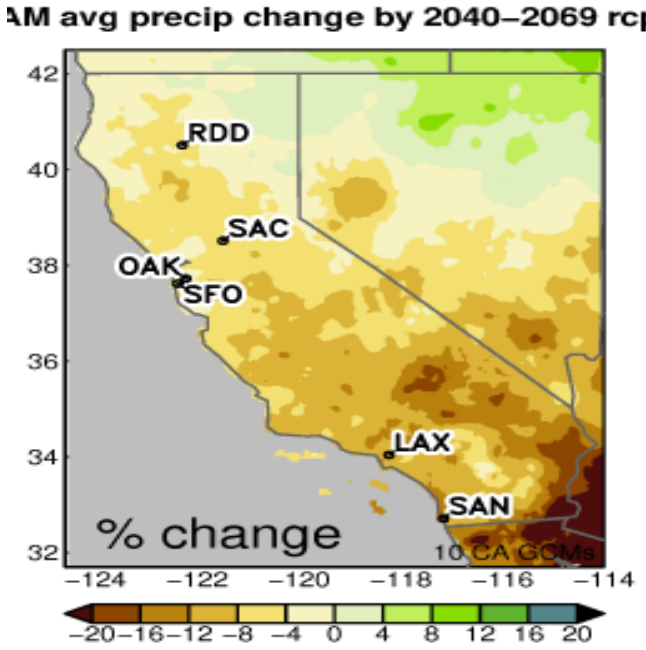
Source: Franco, G., D. R. Cayan, D. W. Pierce, A. L. Westerling, J. H. Thorne. (2018). *Cumulative Global CO_2 Emissions and Their Climate Impacts from Local through Regional Scales*. Publication number: CCCA4-EXT-2018-007.

Timing of precipitation expected to exacerbate California's annual drought

- Wetter winters, drier springs expected by mid-century in California.
- Greater number of precipitation-free days.

Winter precipitation December through February (*left*) and spring precipitation March through May (*right*).



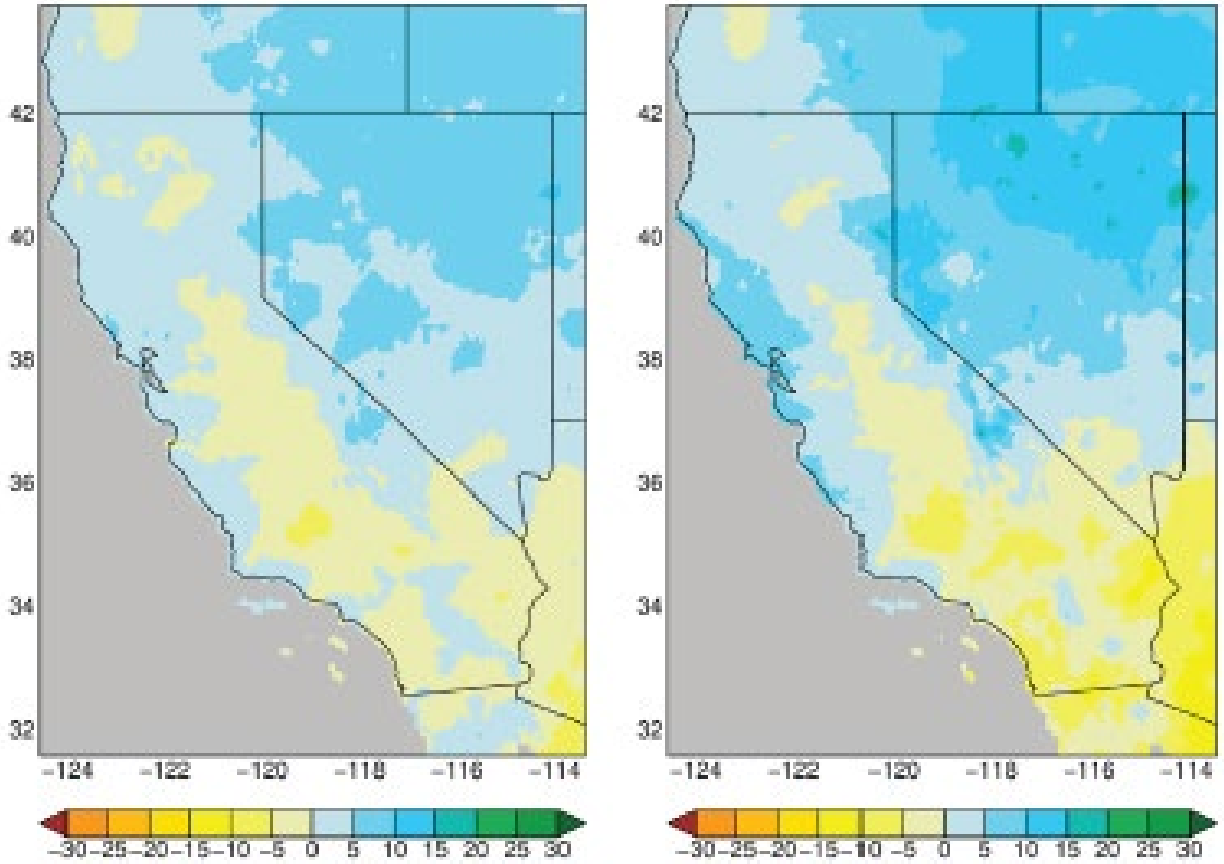


Source: Pierce, D. W., D. R. Cayan, J. F. Kalansky (2018). *Climate, Drought, and Sea Level Rise Scenarios for the Fourth California Climate Assessment*. Publication Number: CCCA4-CEC-2018-006.

Within California, a wetter north and a drier south in terms of precipitation

Ensemble average of 10 downscaled global climate models suggests a slightly drier south and wetter north.

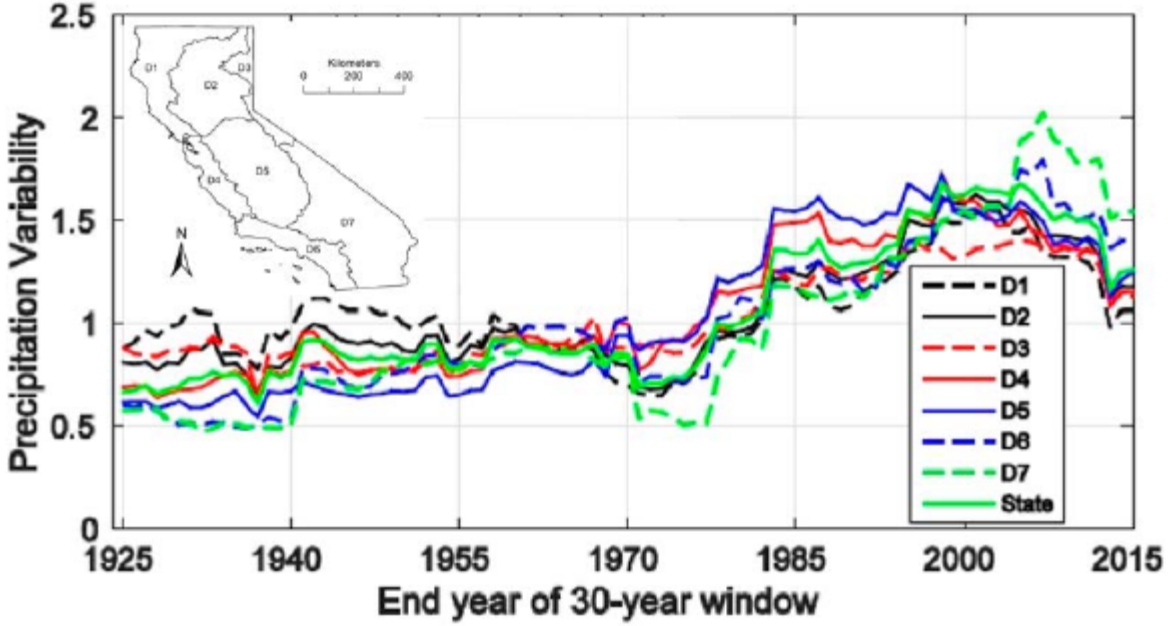
Relative to 1950-2005, RCP4.5 (left) and RCP8.5 (right) suggest that by end-century (2070-2099), Southern California will receive less precipitation on average, with Northern California getting slightly more.



Source: Bedsworth et al (2018). *Statewide Summary Report*. California's Fourth Climate Change Assessment.

Variability of annual precipitation statewide has increased since 1980's

Statewide as well as in regions within California, precipitation variability has increased since the early 1980's.



Source: He M and Guatam M (2016). Variability and trends in precipitation, temperature and drought indices in the state of California. **Hydrology** 3(2): 14.

As presented in *Indicators of Climate Change in California* (2018).

* *30-year moving window of annual precipitation variability statewide, and for NOAA climate divisions (see map, inset). For each year, the value shown is the ratio of the variance for the 30-year period ending in that year to the variance over the entire period. A ratio above 1 means precipitation was more variable; below one, less variable.*

Variability of precipitation expected to continue to increase, leading to more dry years

A trend of fewer wet days but higher daily maximum precipitation drives an increase in year-to-year variability and more frequent dry years.

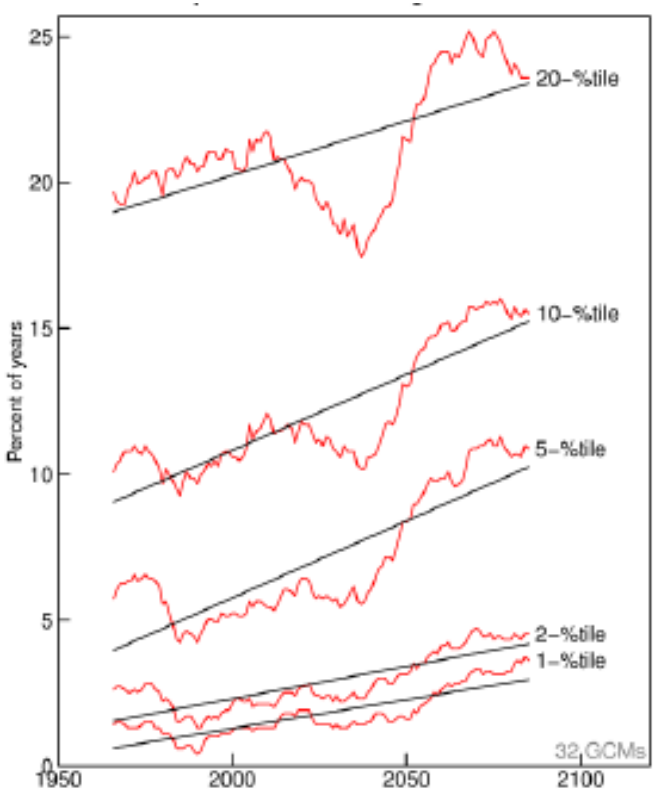


Figure: The ensemble of 32 GCMs downscaled by LOCA shows an increasing frequency of years that are drier than various historical percentiles.

Source: Pierce et al (2018). *Climate, Drought, and Sea Level Rise Scenarios for the Fourth California Climate Assessment*. Publication Number: CCCA4-CEC-2018-006.

Extreme precipitation events are projected to become more intense and frequent

Extreme precipitation expected to increase in most cities in California.

- Frequency of today's 50-year event could double in both Southern California and Northern California.
- Changes in projected intensity of extremes is more pronounced for RCP8.5.

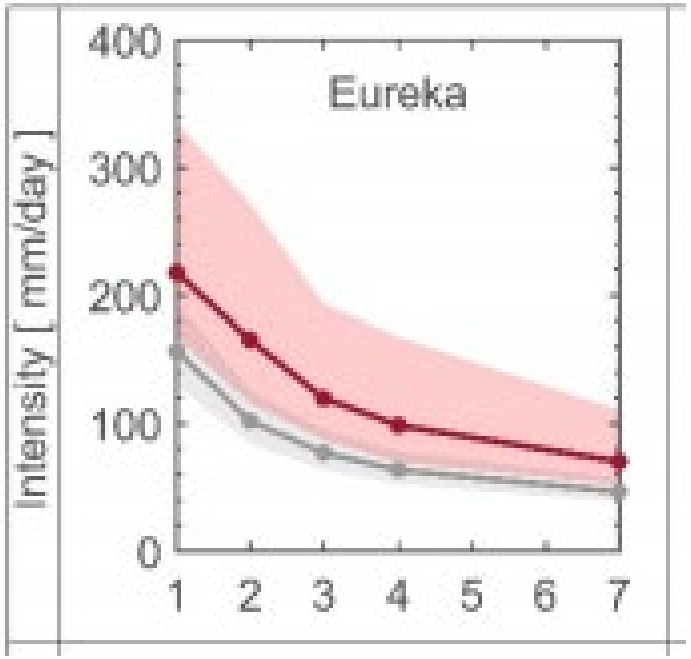


Figure: Comparison between historical (1950-1999, grey) and future (2050-2099, red) projected 100-year Intensity-Duration-Frequency curves for RCP8.5 in Eureka, California. 90% confidence intervals indicated by pink and grey shading.

Source: AghaKouchak, Amir, Elisa Ragno, Charlotte Love, and Hamed Moftakhari (2018). *Projected Changes in California's Precipitation Intensity-Duration-Frequency Curves*. California's Fourth Climate Change Assessment, California Energy Commission. Publication Number: CCCA4-CEC-2018-005.

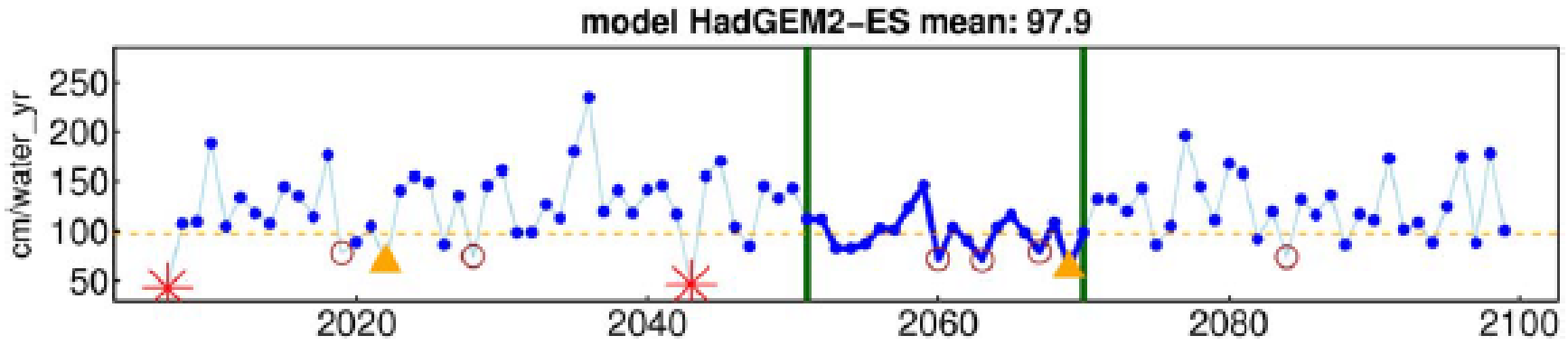
See also: https://cal-adapt.org/tools/extreme-precipitation/

Extended droughts may become more likely

Persistent droughts evidenced by the paleorecord may become more likely based on both moderate and high emissions model projections.

Source: Cook et al (2015). Unprecedented 21st century drought risk in the American Southwest and Central Plains. *Science Advances*.

- Projections developed for the Fourth Assessment include two 20-year drought scenarios.
- Climate and hydrological data are available on Cal-Adapt* for near-term (2023-2042) and late-century (2051-2070) droughts.
  * https://cal-adapt.org/tools/extended-drought/



Source: Pierce et al (2018). *Climate, Drought, and Sea Level Rise Scenarios for the Fourth California Climate Assessment*. Publication Number: CCCA4-CEC-2018-006.

Coastal and Central Valley fog: further investigation needed

Fog plays a vital role in local climate, ecosystems, & agriculture. However,

- Trends in coastal fog are uncertain: ship-based observations, backcast analysis driven by measurements of cloud ceiling heights at airports, and dynamic simulations are not in agreement regarding trends in California's coastal fog (OEHHA 2018).
- Central Valley Fog: satellite data, field measurements, and human experience indicate a decreasing trend (OEHHA 2018).
  - Substantial decreases have been observed since 1980.
  - Reduced atmospheric particulate matter (PM) may be the dominant driver of long-term spatial and temporal changes (Gray et al. 2019).

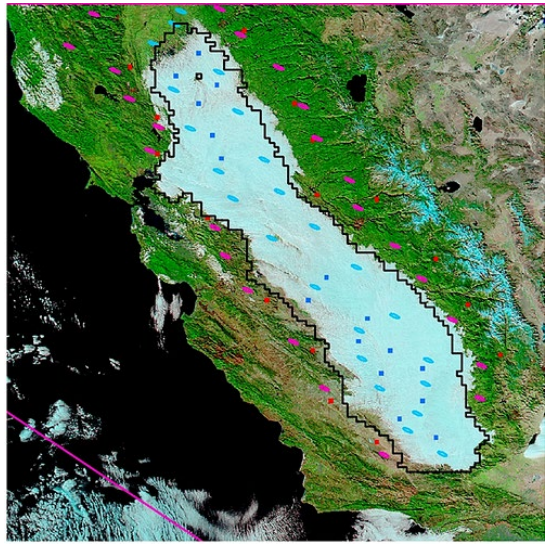


Figure: Satellite-based observations of tule fog in the Central Valley on December 2, 2008.

Source: Baldocchi and Waller (2014). "Winter fog is decreasing in the fruit growing region of the Central Valley of California." *Geophysical Research Letters*, 41(9).

Publicly available tools for exploring projected climate risks to California

Conclusion

- Since 1989, **atmospheric CO_2 has continued to rise**, from 355 to 415 ppm
- **Climate change is already affecting California in ways anticipated in 1989**
  - Reduced spring streamflow, increase winter streamflow
  - More precipitation falling as rain
- **Projections have also illuminated:**
  - A “drier” state is expected in terms of soil moisture, even as mean statewide precipitation remains uncertain.
  - Timing of precipitation expected to exacerbate drought-related risks.
  - Distribution of precipitation reveals regional differences: wetter north, drier south.
  - Extremes are expected to become more pronounced with greater variability of precipitation.
- **Effect of climate change on fog** merits further inquiry