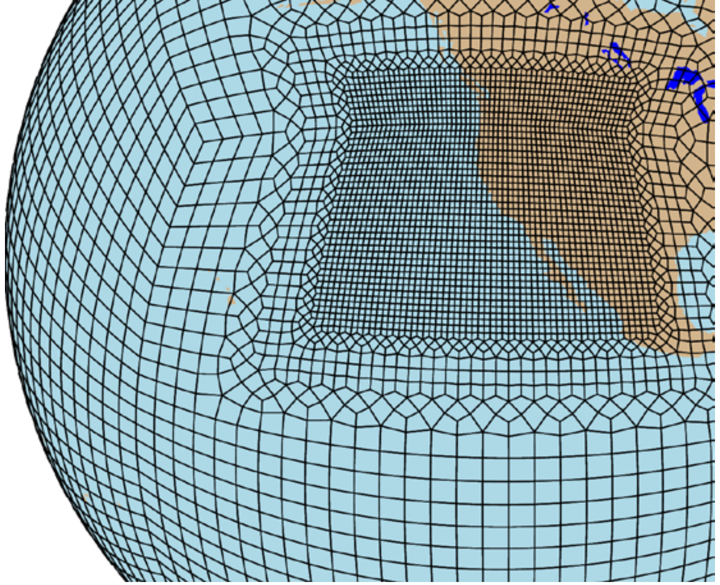



A Review of Recent Advances in Climate Modeling Across Scales

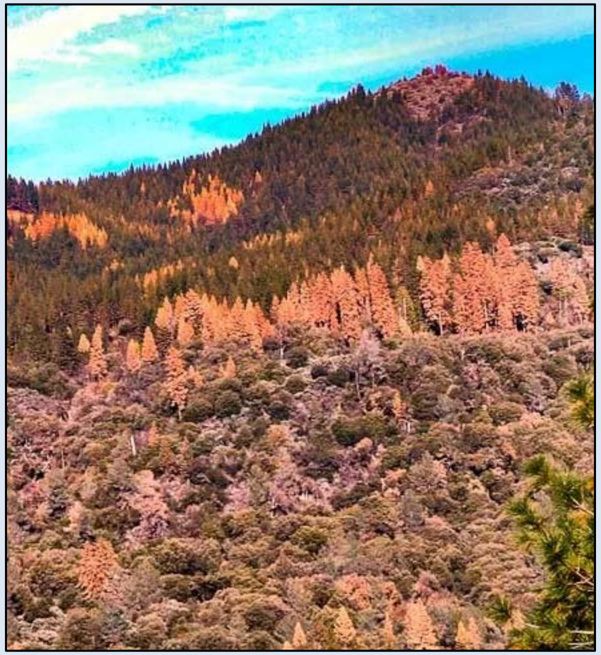
Paul Ullrich, University of California Davis

Image credit Justin Sullivan/Getty

Why Modeling Across Scales?

There is a clear need for high-resolution, high-quality climate data for use by stakeholders and policymakers.

Water availability



Ecosystem health

Heat stress

Air Quality

Why Modeling Across Scales?

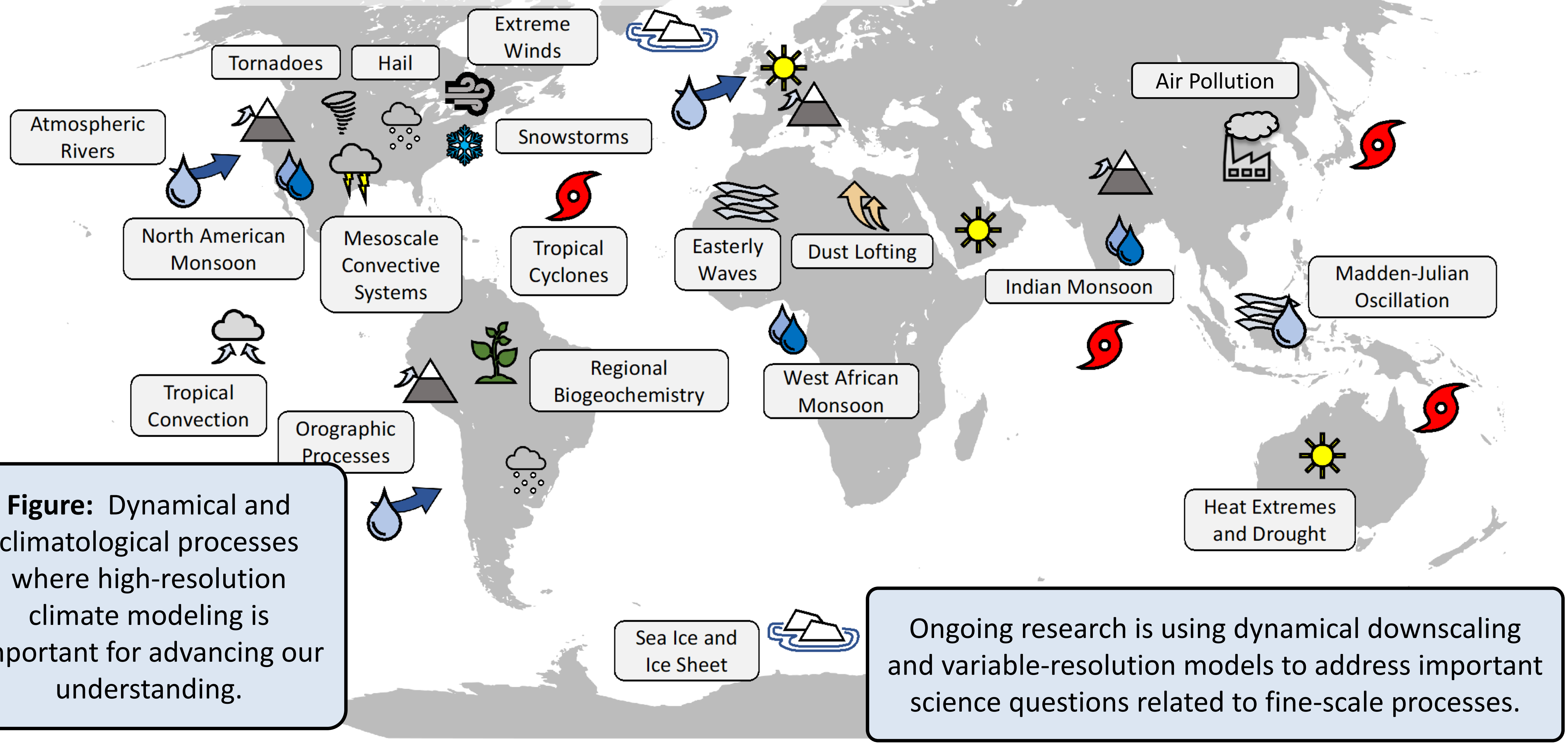


Figure: Dynamical and climatological processes where high-resolution climate modeling is important for advancing our understanding.

Ongoing research is using dynamical downscaling and variable-resolution models to address important science questions related to fine-scale processes.

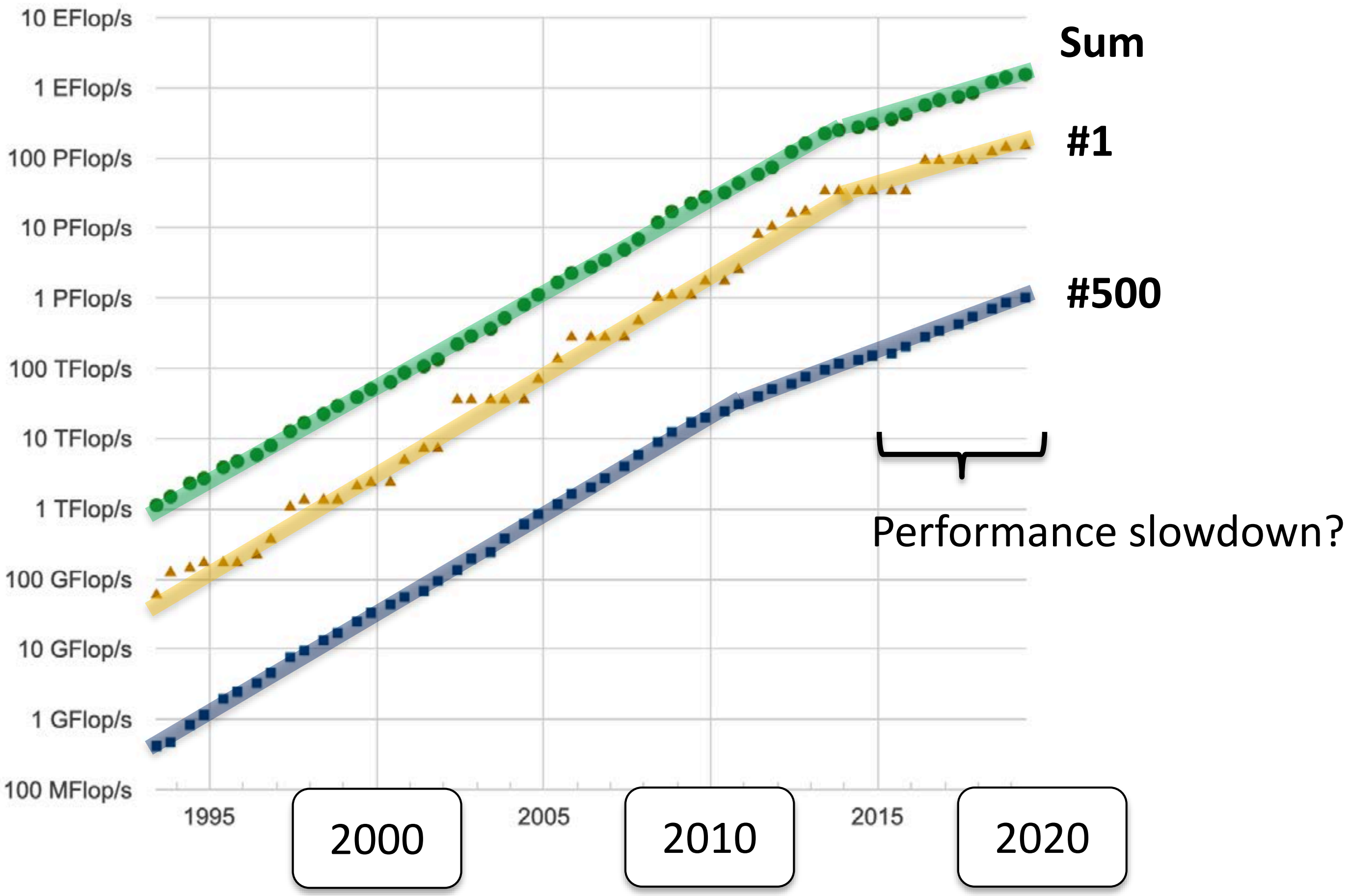
Computing Power

High-resolution studies have been largely enabled by rapidly advancing computing power.

Computational power doubles approximately every 1.2 years (although it's been slowing down).

To obtain a factor of 2 horizontal refinement, numerical models require 8x the computational power.

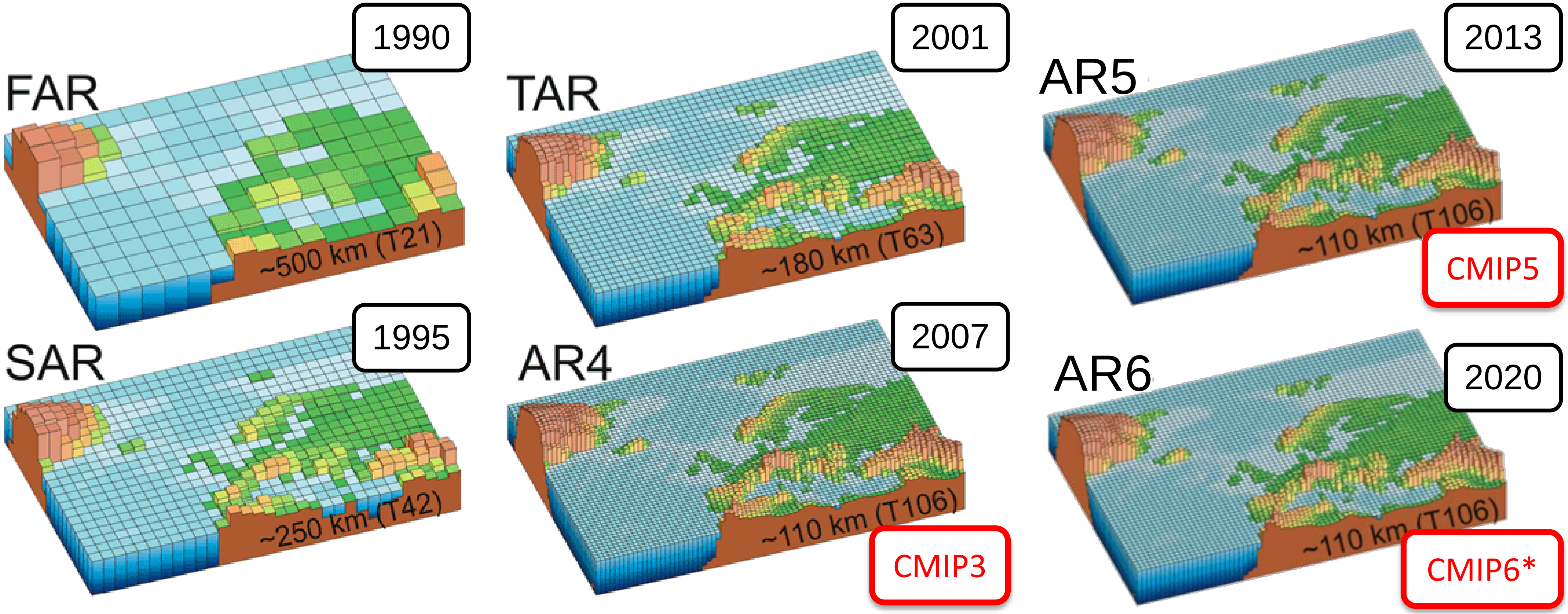
→ Doubling of horizontal resolution every 3.6 years?



Global Climate Model Resolution

Typical Intergovernmental Panel on Climate Change (IPCC) model resolutions.

However, operational global model resolution has largely stagnated for climate simulations.



*HighResMIP, part of CMIP6, compares models at resolutions of 25km and 50km.

Regional Climate Model Resolutions

Although GCM resolution has stagnated, several projects have pushed RCM resolutions higher by leveraging trade-offs with domain size.

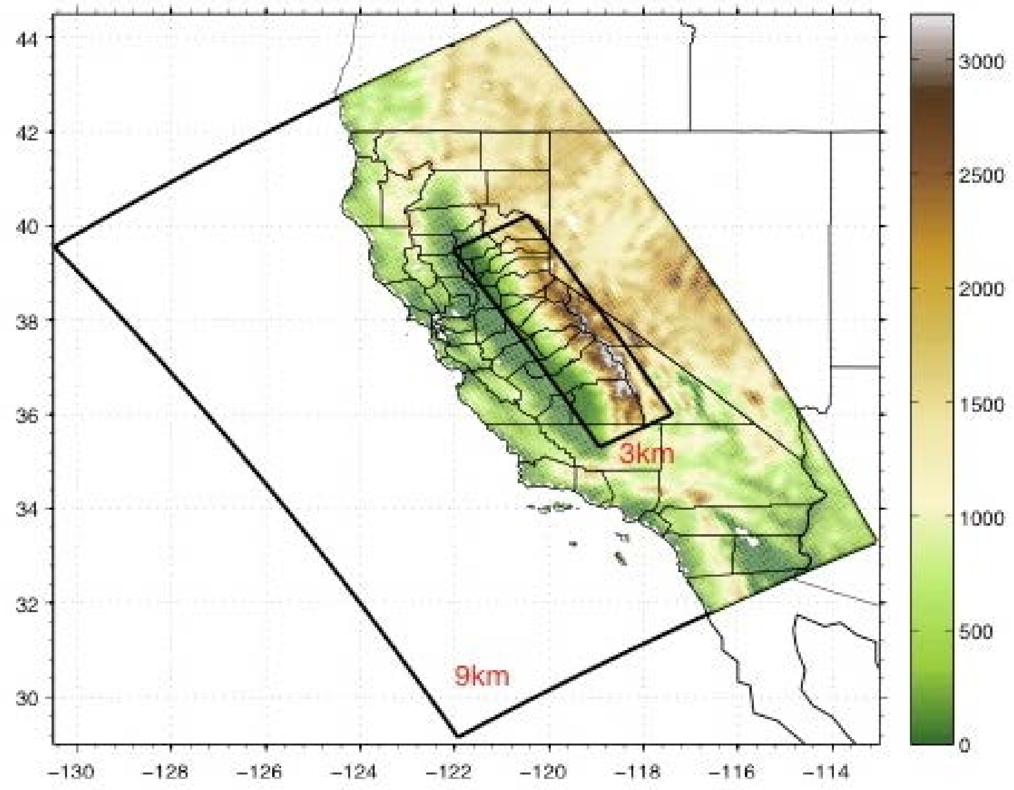
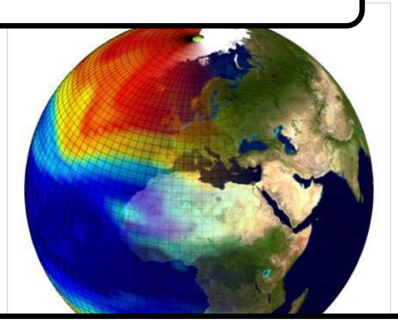


Figure: A 3km simulation domain over the Sierra Nevada used in a WRF modeling study by Alex Hall, Xingying Huang, and Neil Berg at UCLA.

High-Resolution via Downscaling

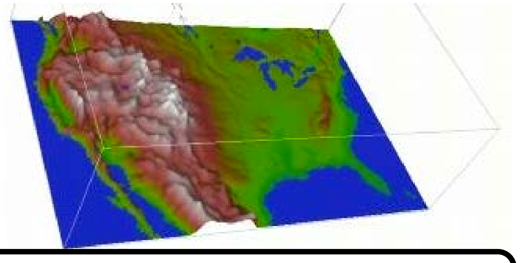
Global models



100 km grid spacing

No explicitly driven boundary conditions except at the surface and the top-of-the-atmosphere.

Regional models



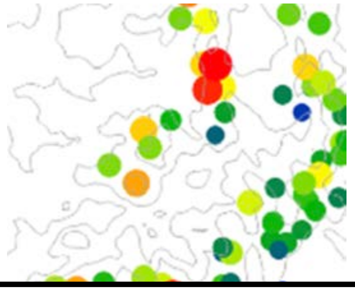
3-25 km grid spacing

Lateral boundary conditions must be specified.

High-resolution is typically achieved by downscaling global atmospheric models which have been run at coarse resolution.

Dynamical Downscaling

Local scales



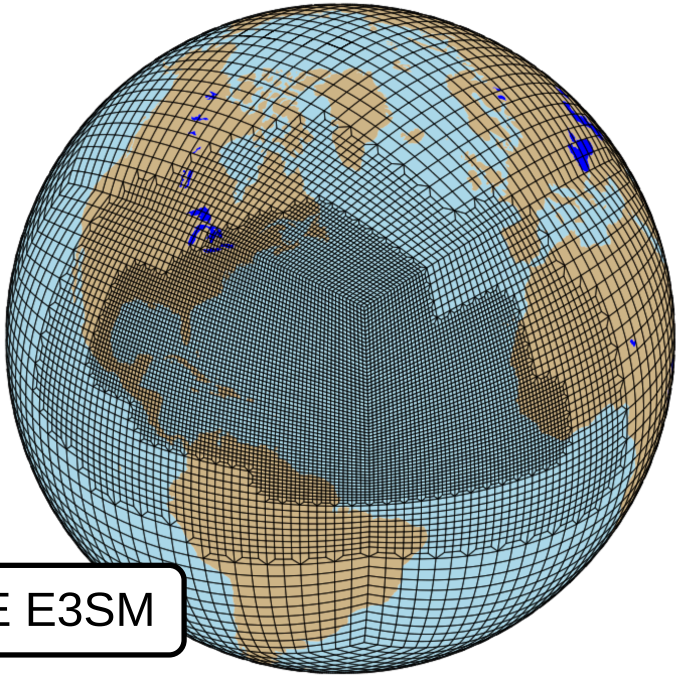
Pointwise Data

Statistical downscaling (global to local)

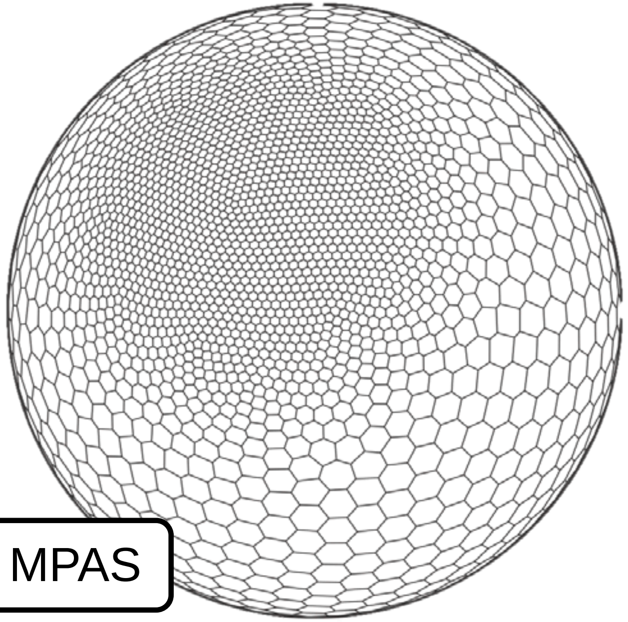
Statistical downscaling (regional to local)

High-Resolution via Variable-Resolution

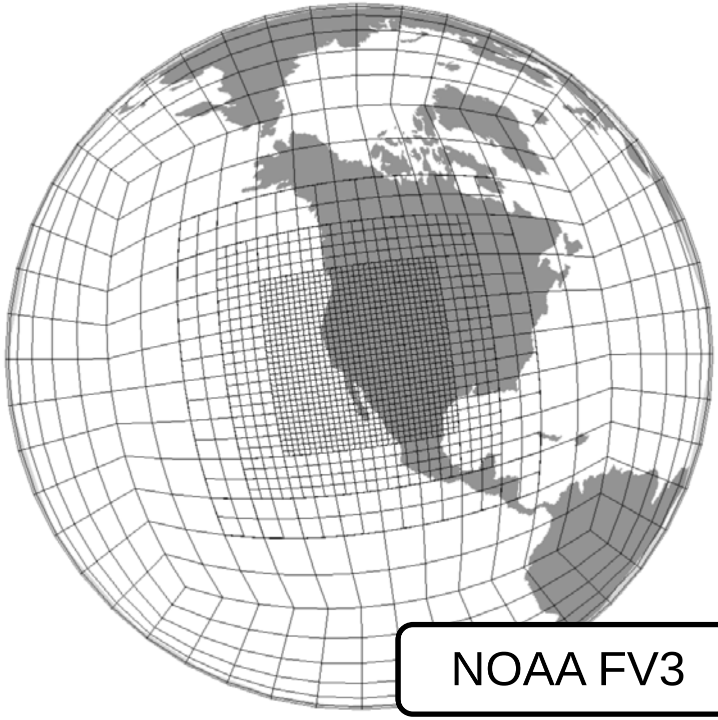
However, global atmospheric models with enhanced resolution where needed are growing increasingly popular.



DOE E3SM



NCAR MPAS

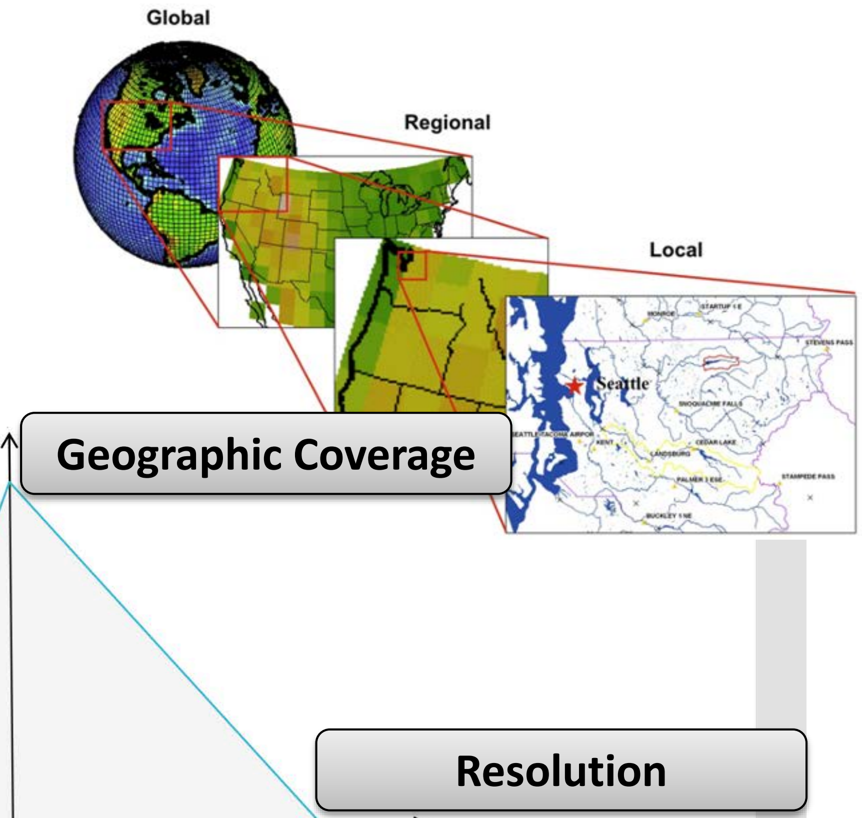


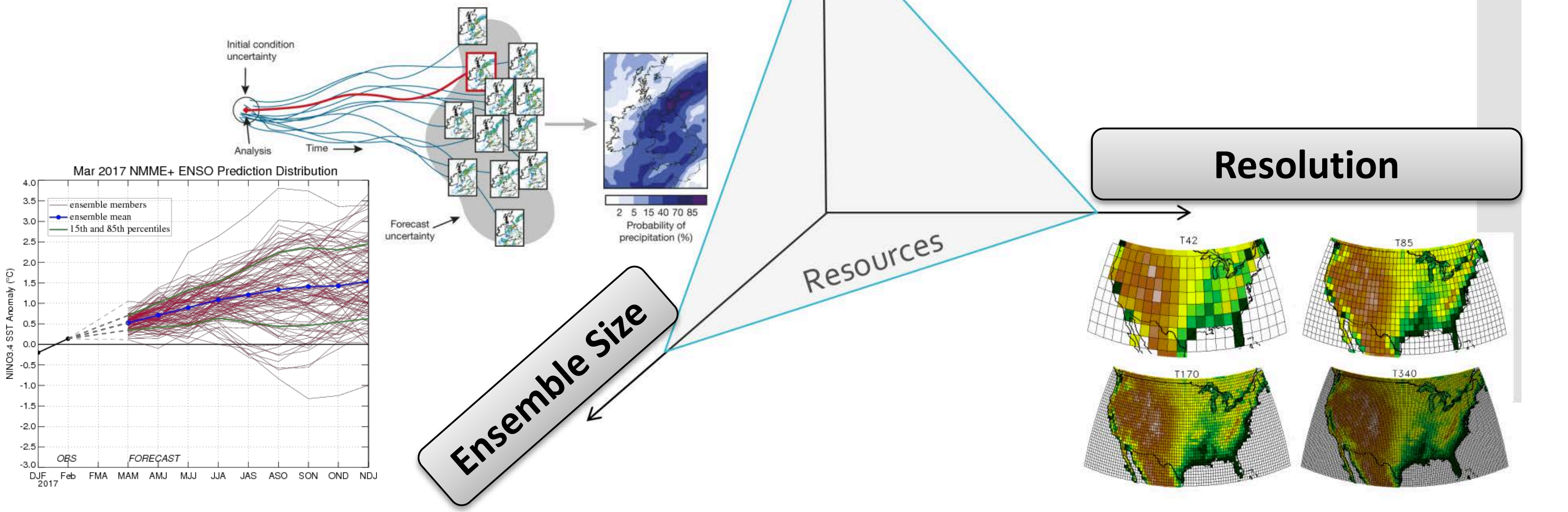
NOAA FV3

Balancing Utility with Constrained Resources

Given limited computational resources we must balance **geographic coverage**, **model resolution**, and **ensemble size**.

Additional factors include **temporal period**, **data storage**, and **model complexity**. Each of these are individually valuable for regional modeling assessment.





Dynamical Downscaling Experiments: A Taxonomy

Reanalysis-driven Downscaling

Given observed synoptic conditions, how well does the RCM simulate mean climate and regional phenomena-of-interest (e.g., MCSs)?

AOGCM-driven Downscaling (Historical)

- Given historical AOGCM synoptic conditions, does simulation quality change compared with reanalysis?
- Establish a baseline for future climate simulations.

AOGCM-driven Downscaling (Future)

How might mean regional climate and/or phenomena-of-interest change with future climate forcings?

Modified Boundary Condition Experiments

Mechanistic Experiments (Historical)

How does a feature or region's behavior change in the absence or presence of a given boundary forcing?

Pseudo-Global Warming (Future)

How would historically-observed weather (events) change in light of global climate change?

California's Drought of the Future (2042-2047)

Paul Ullrich, University of California Davis

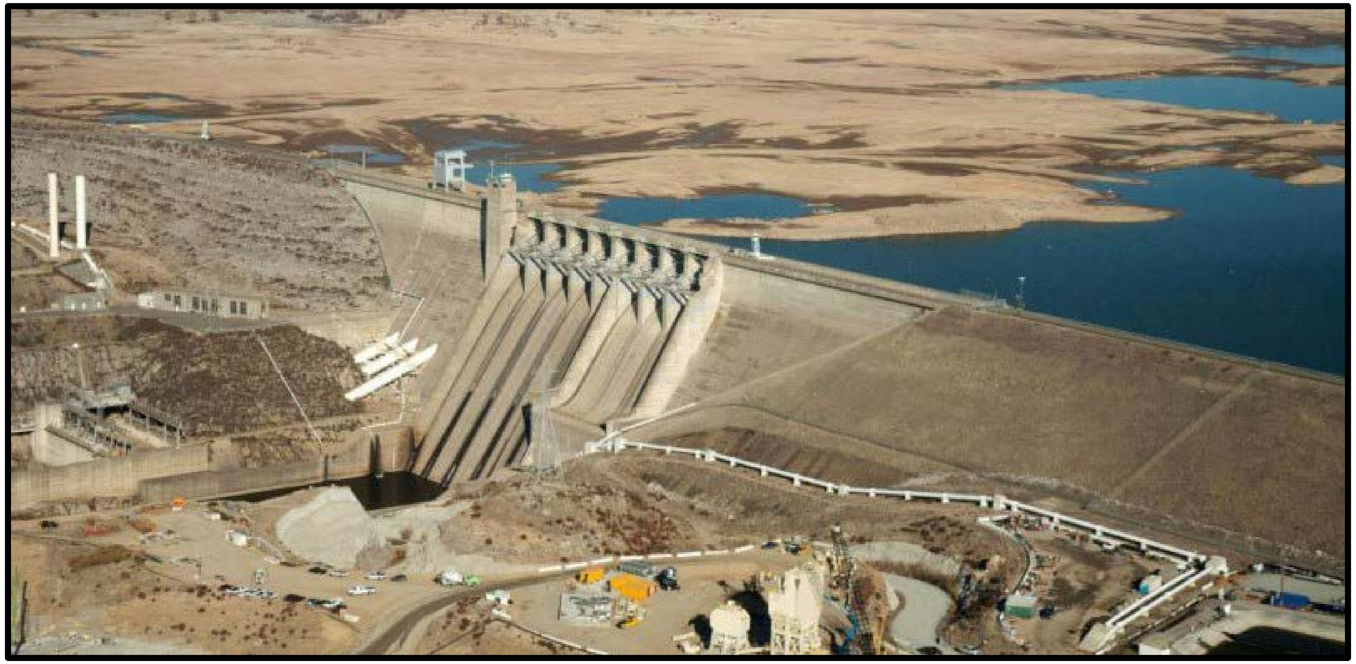
Zexuan Xu, Lawrence Berkeley National Laboratory
Alan Rhoades, Lawrence Berkeley National Laboratory
Michael Dettinger, Desert Research Institute
Jeffrey Mount, Public Policy Institute of California

Image credit Justin Sullivan/Getty

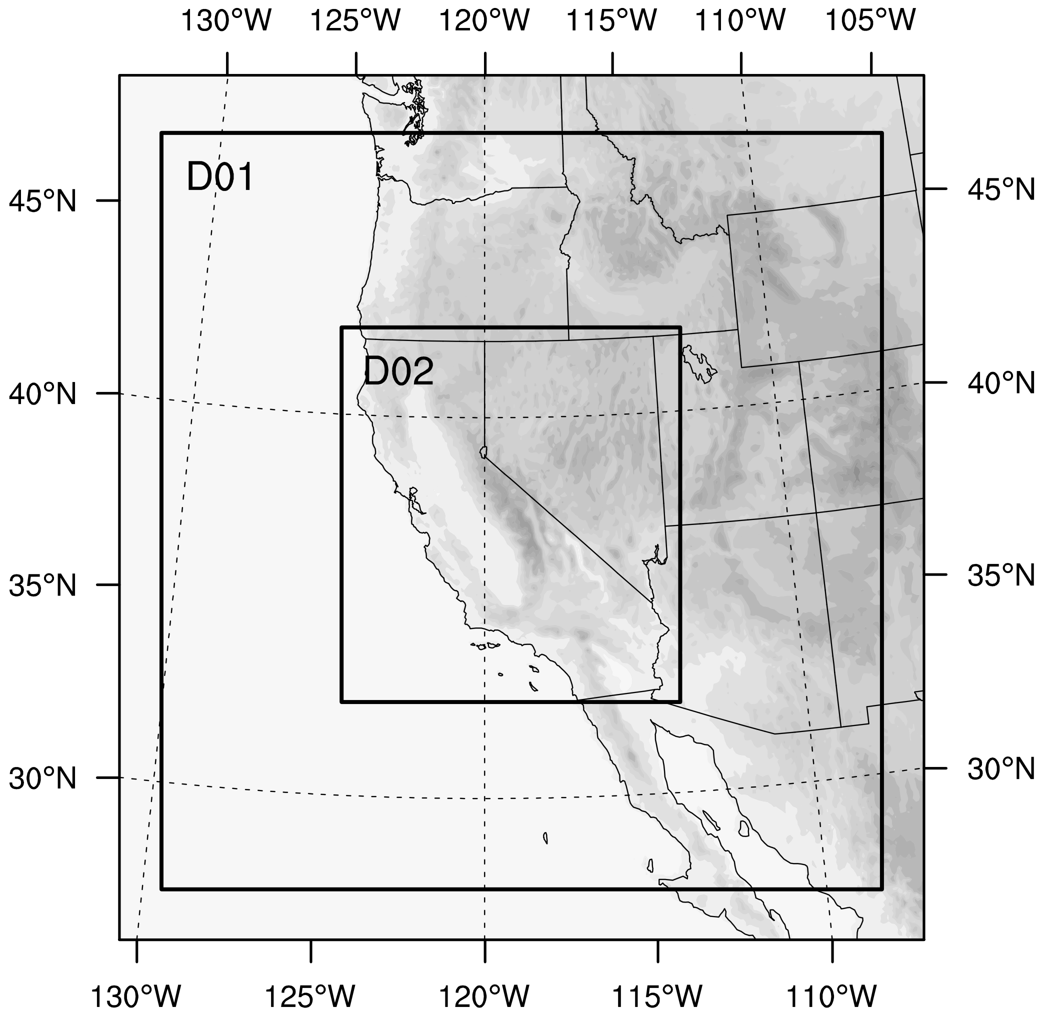
2012-2016 California Drought

Persistently dry conditions were experienced by California over this period, finally broken up by the anomalously wet winter of 2016-2017.

As of October 2016, California had an accumulated **“rain debt”** from the 2012-16 period equal to **one year of average precipitation**.



Building a Drought of the Future



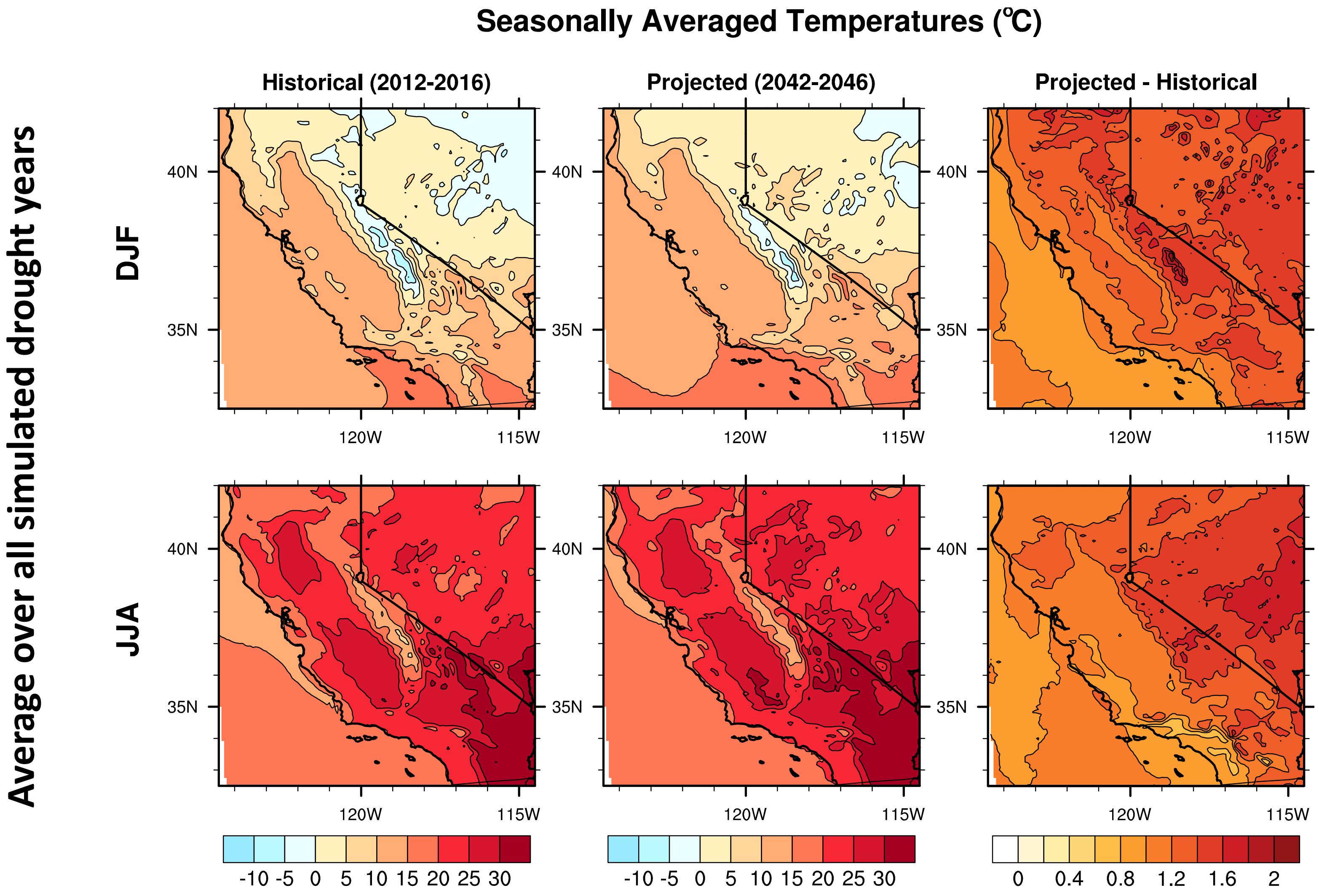
Model: Weather Research and Forecasting (WRF) model with Community Land Model (CLM) land surface.

Domain (Figure): High-resolution (9km) WRF simulation domain in.

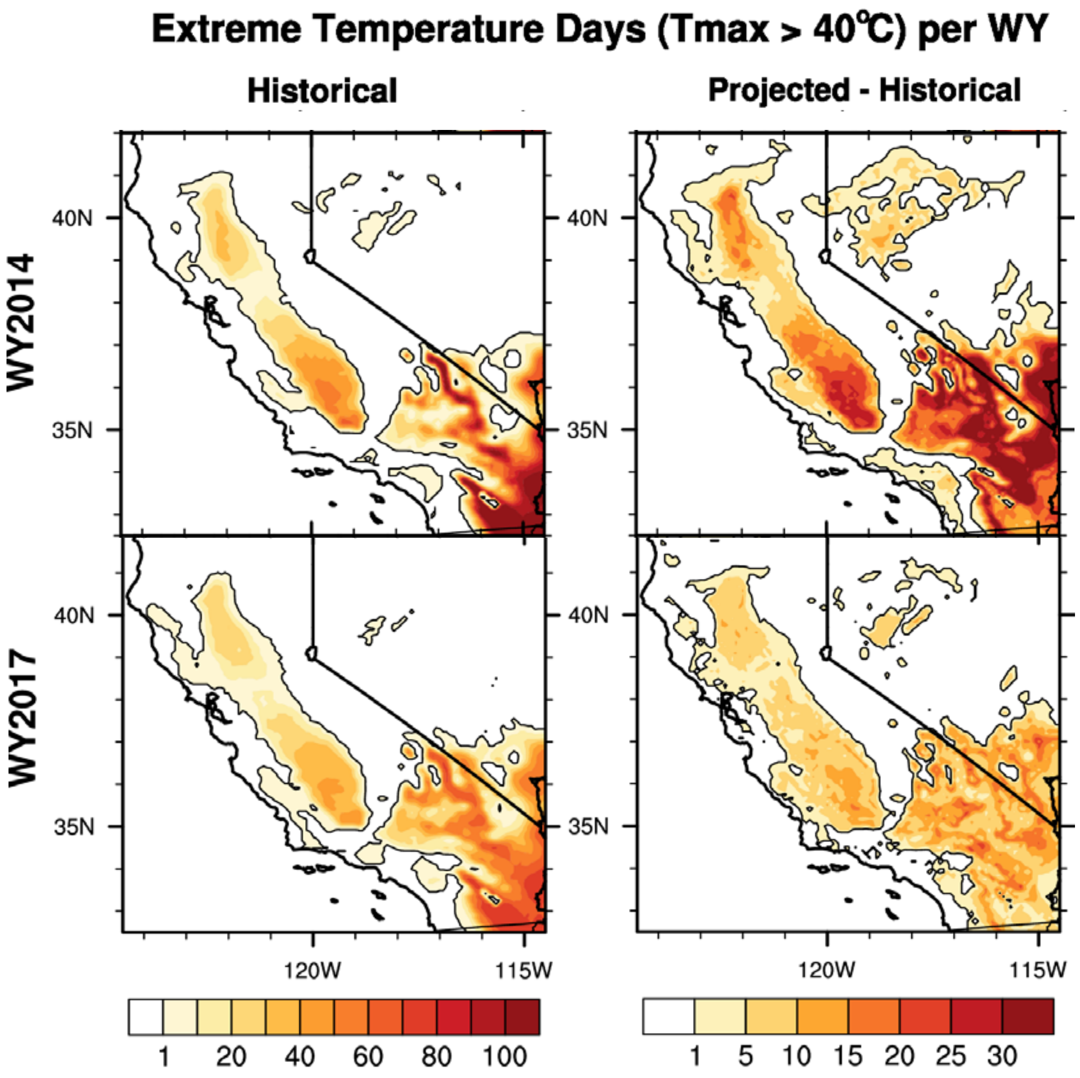
Simulation Period:
Historical: 06/01/2012 – 08/31/2017
Projected: 06/01/2042 – 08/31/2047

Validation against historical climate observations showed exceptional agreement.

Temperature Projections



Extreme Heat Days

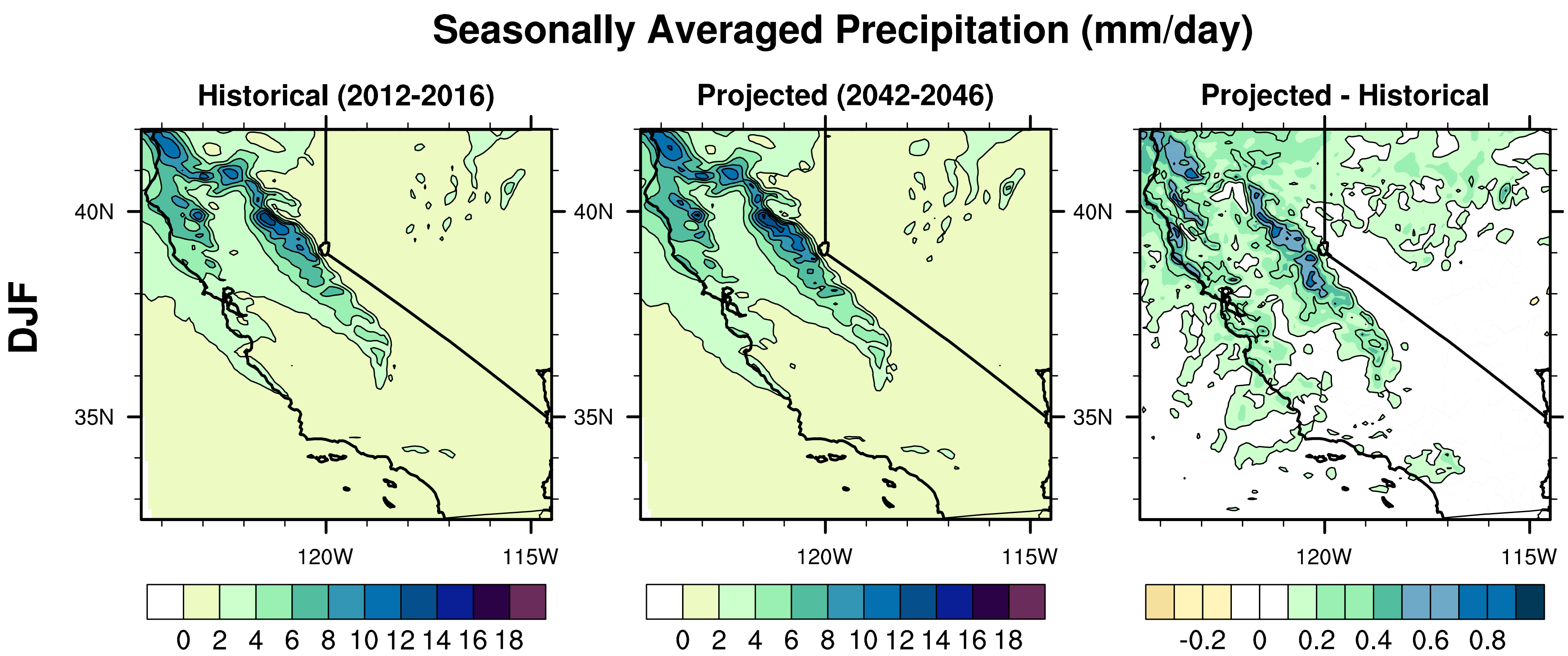


Exceptionally Dry Year

Exceptionally Wet Year

More extreme heat days in dry years

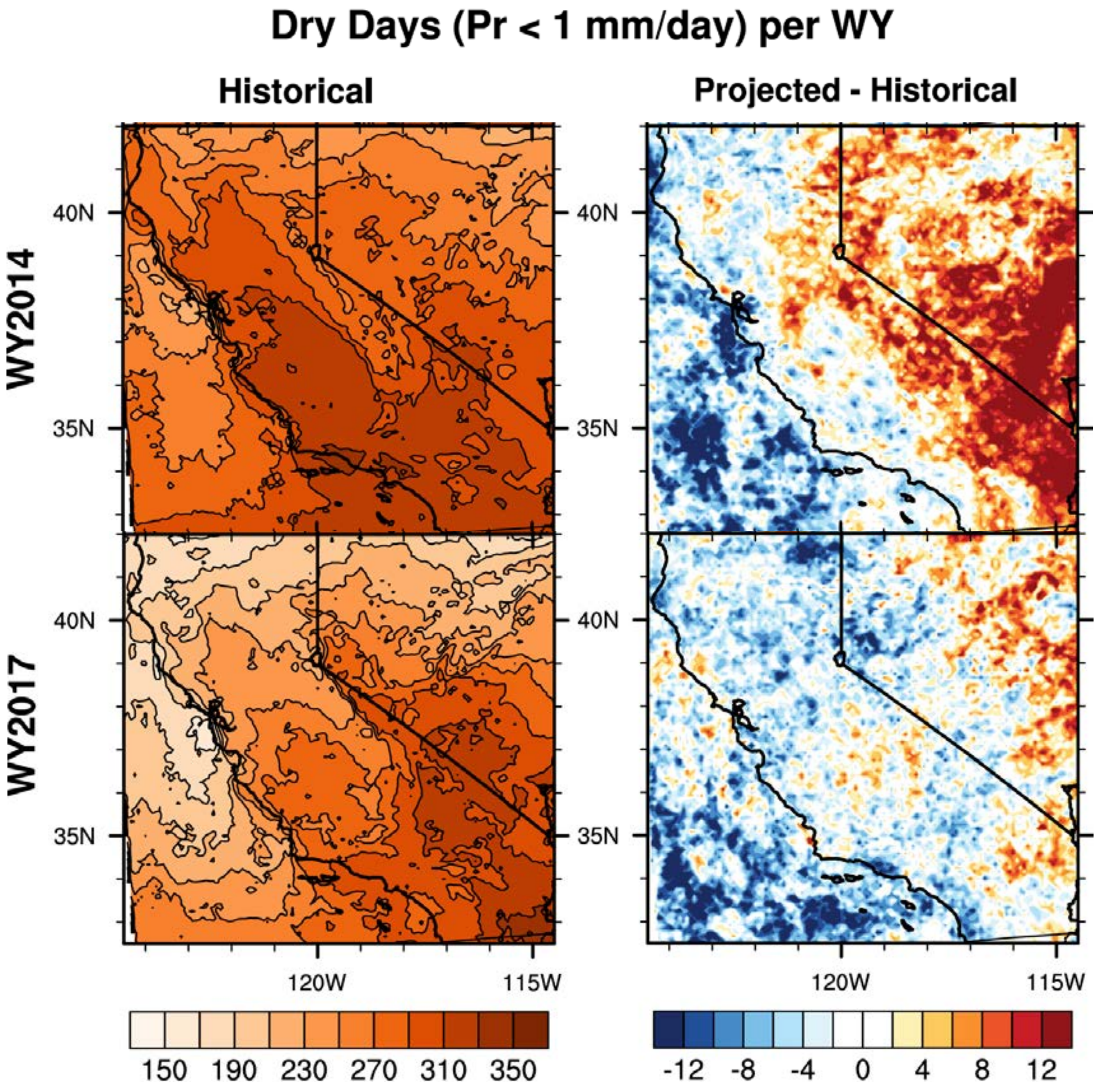
Precipitation Projections



Increase in DJF precipitation in accordance with theoretical scaling (~6% / degree C)

Dry Days

More dry days in dry years

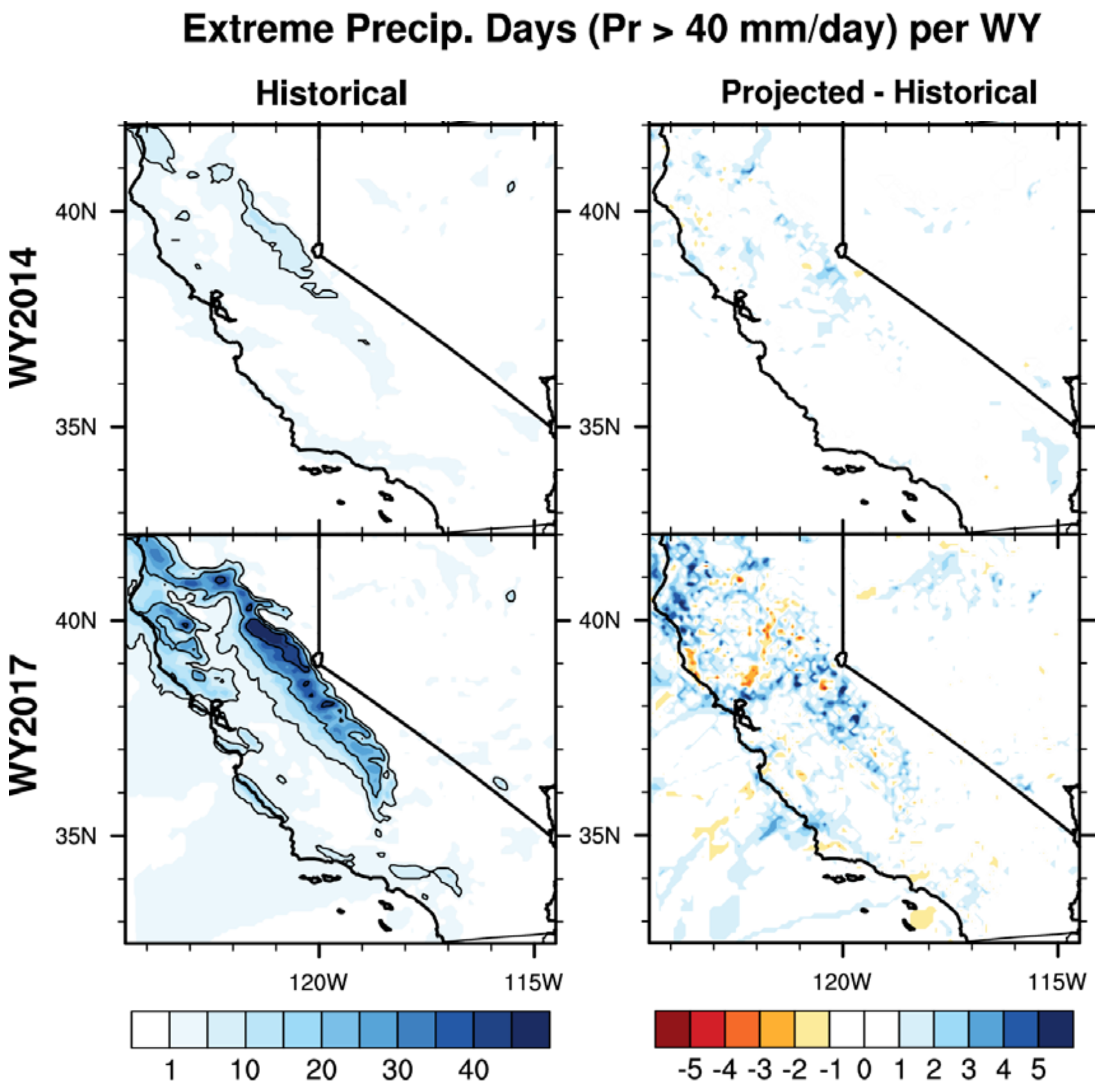


Exceptionally Dry Year

Exceptionally Wet Year

Extreme Precipitation Days

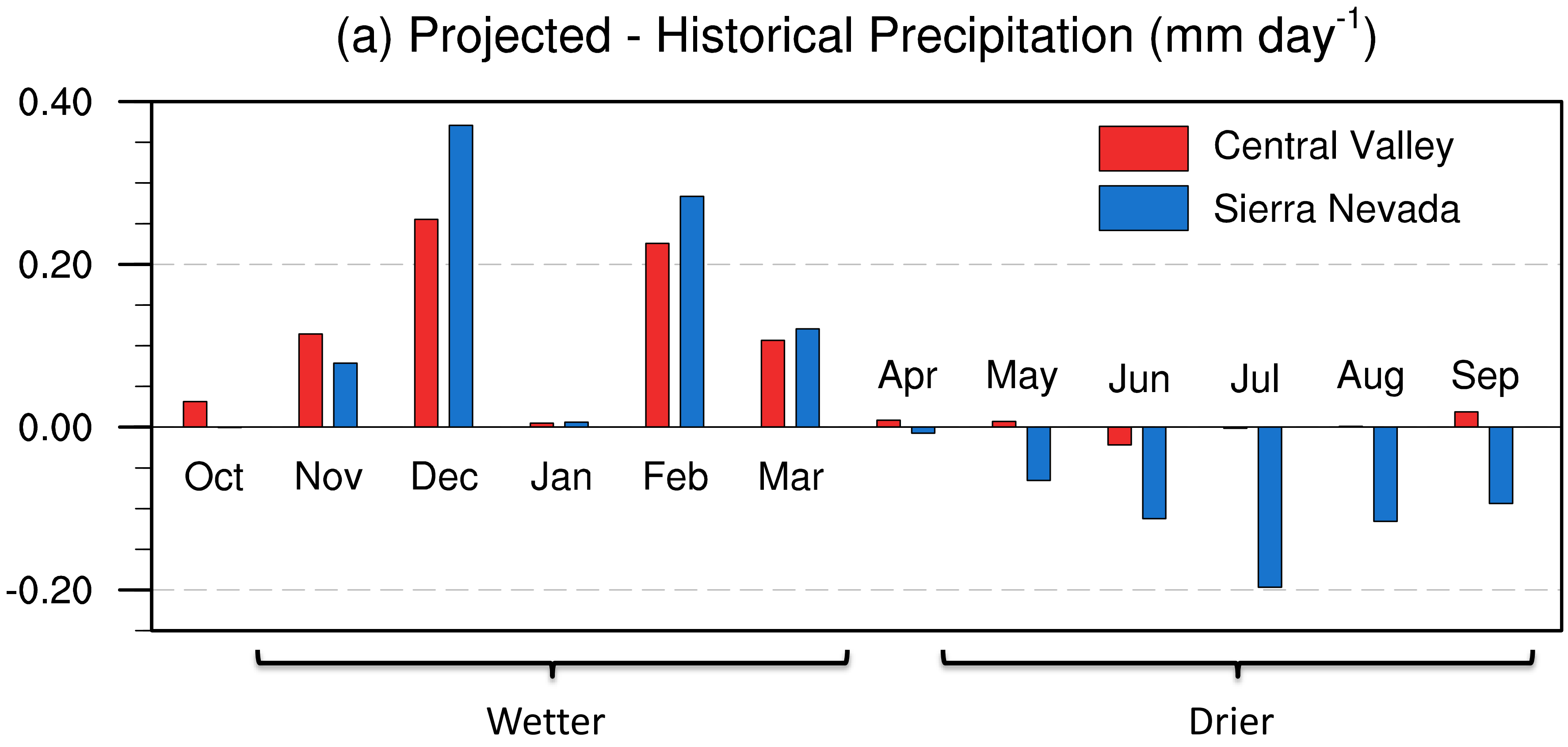
More extreme precipitation days in wet years



Exceptionally Dry Year

Exceptionally Wet Year

Changing Seasonality

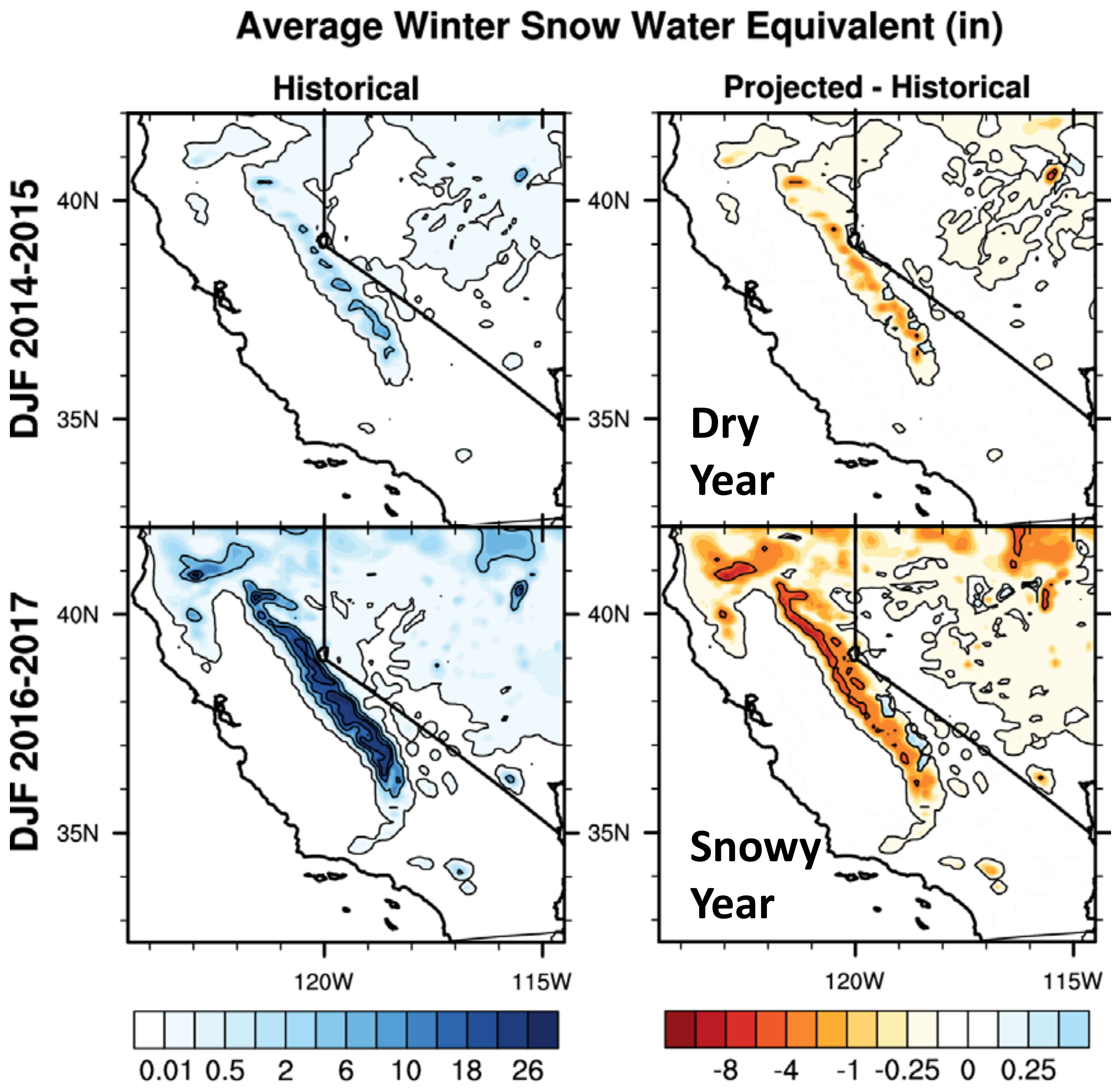


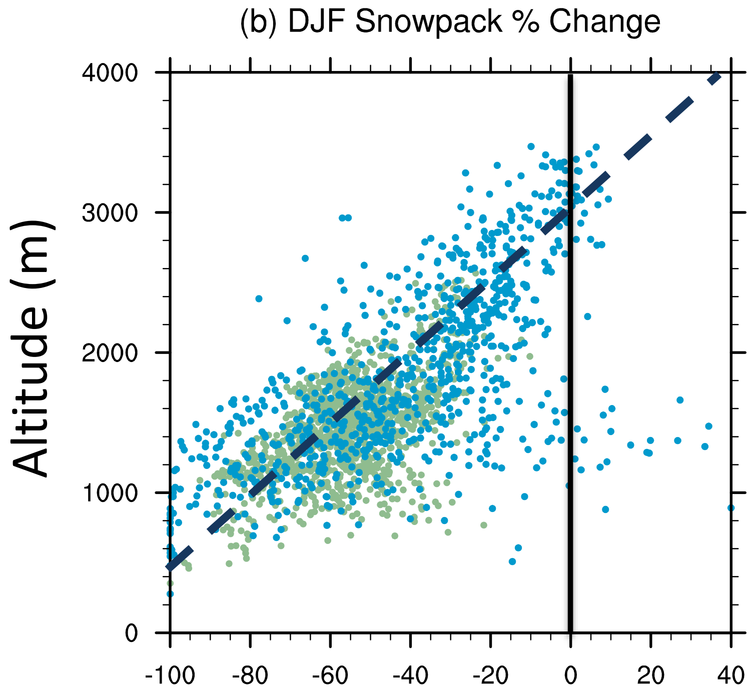
There will be an increased seasonality of precipitation:
Wet winters become wetter, dry summers become drier.
Wet years become wetter, dry years become drier.

Mountain Snowpack

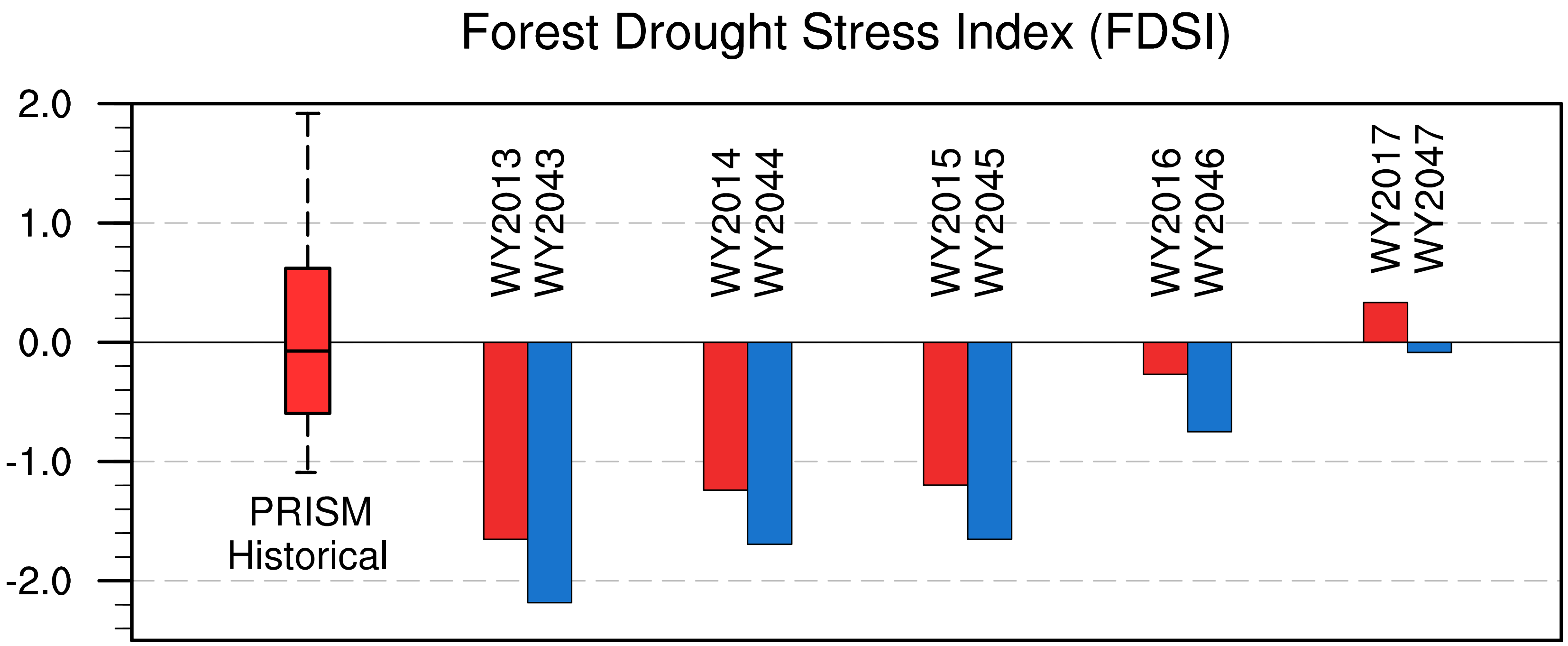
Because of increased temperatures, increased precip. does not translate to increased snowpack.

Simulated peak total **snow water equivalent (SWE)** diminished between **16% to 30% across** the five water years from 32.6 MAF to 25.5 MAF, **a net loss of 7.1 MAF or 22%.**





Forest Stress

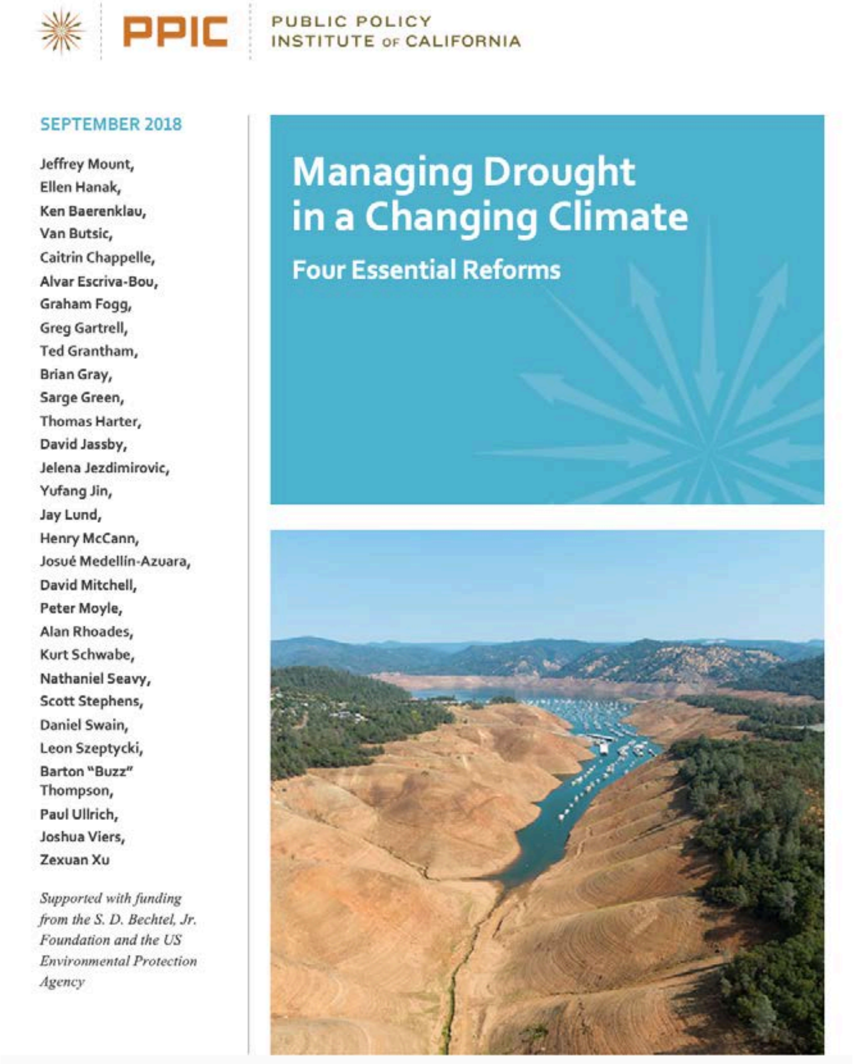


Result: Unprecedented forest stress, expected to lead to widespread loss of our montane forests to drought, wildfire, and infestation.

California’s Drought of the Future

Ullrich, P.A., Z. Xu, A.M Rhoades, M.D. Dettinger, J.F. Mount, A.D. Jones, and P. Vahmani (2018) "**California's Drought of the Future: A Midcentury Recreation of the Exceptional Conditions of 2012-2017**" *Earth's Future*, Volume 6 (11), pp. 1568-1587, doi: 10.1029/2018EF001007.

Mount, J. et al. (2018). “***Managing Drought in a Changing Climate: Four Essential Reforms***.” Published by the Public Policy Institute of California, September 2018.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Managing Drought in a Changing Climate

Four Essential Reforms

Thank You!

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