



21st century projections for Western US snowpack and seasonal runoff

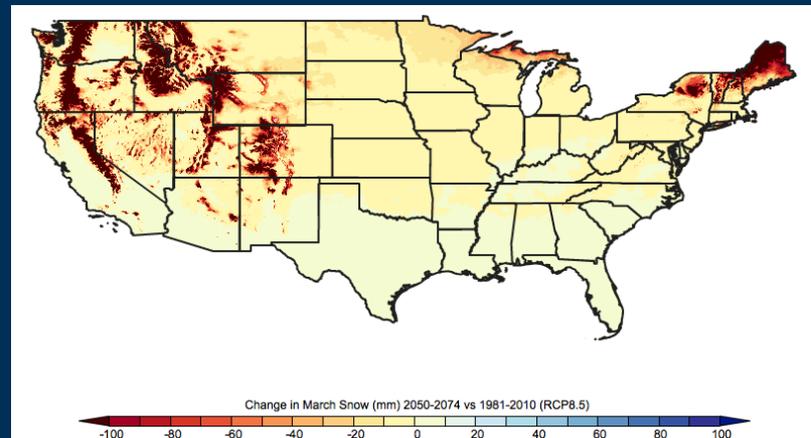
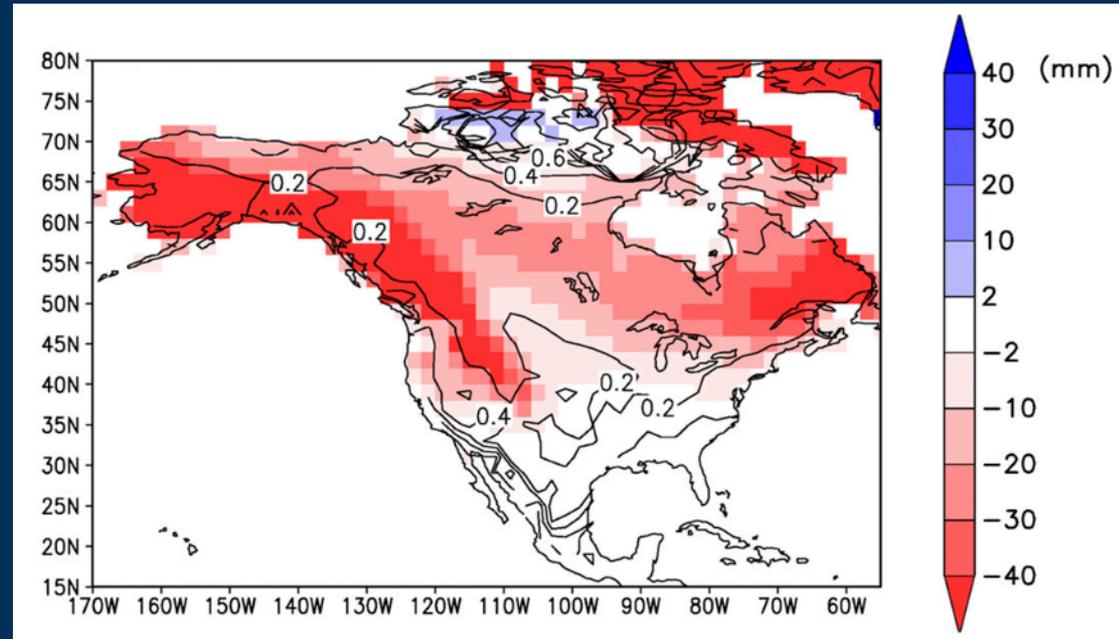
Jay Alder, Steve Hostetler

US Geological Survey

Translating global model information to regional scales

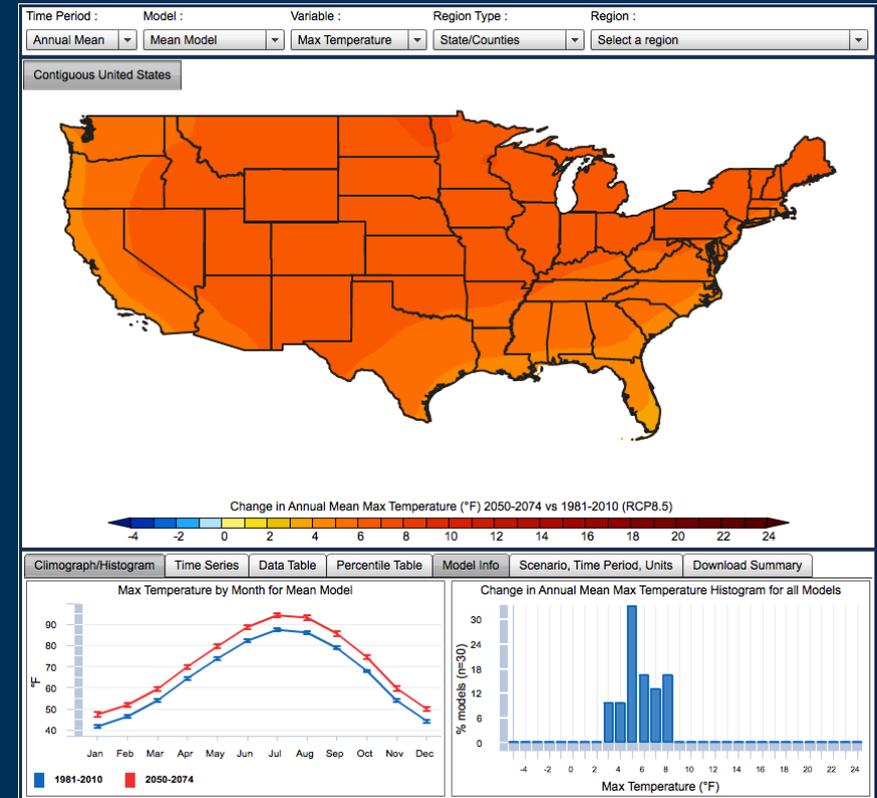
Maloney, et al., 2014

- GCM scale analysis
- Dynamical downscaling (RCMs)
- Statistical downscaling to process models



USGS National Climate Change Viewer: hydroclimate dataset

- Monthly water-balance model
 - McCabe & Wolock
- Modified to include time-varying degree-day snow melt factor and spatially varying parameters
- Run over 800 m CONUS grid (12M land grid cells)
- T and P as inputs
- 30 CMIP5 models 1950-2099



Updated December 2016
https://www2.usgs.gov/climate_landuse/clu_rd/nccv.asp

Hostetler, S.W. & Alder, J.R., 2016. Implementation and evaluation of a monthly water balance model over the US on an 800 m grid. *WRR*, 52(12), pp.9600–9620.

Benefits of higher resolution

- Captures topographic features and rough terrain in the West
- Resolves changes in isotherms (ie 0 °C isotherm)
- Area changes in snow covered areas
- Elevational gradients of change
 - Change in snow regimes as precipitation phase changes from snowfall to rainfall

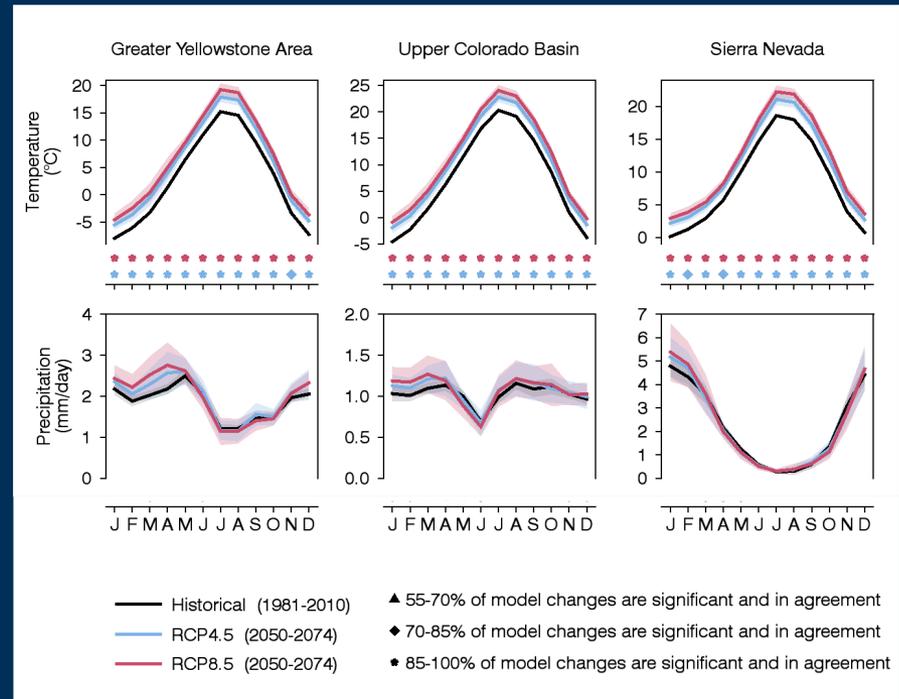
Focus regions

- Greater Yellowstone Area (GYA)
- Upper Colorado Basin (UCB),
- California Sierra Nevada (SN)

- Annual precip change
GYE 8% (3% to 28%)
SN 2% (-24% to 37%)
UCB 5% (-9% to 20%)



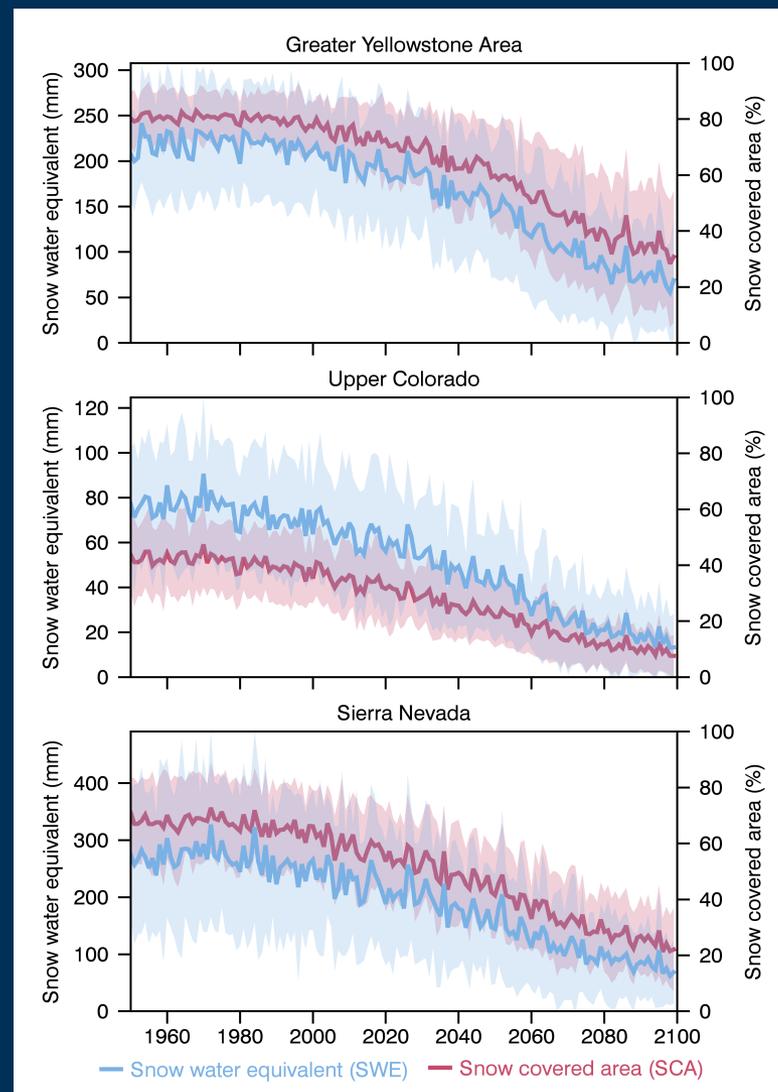
2050-2074 vs 1981-2010



- Annual Temp change
GYE: $3.6\text{ °C} \pm 0.9\text{ °C}$
SN : $3.1\text{ °C} \pm 0.7\text{ °C}$
UCB: $3.6\text{ °C} \pm 0.9\text{ °C}$

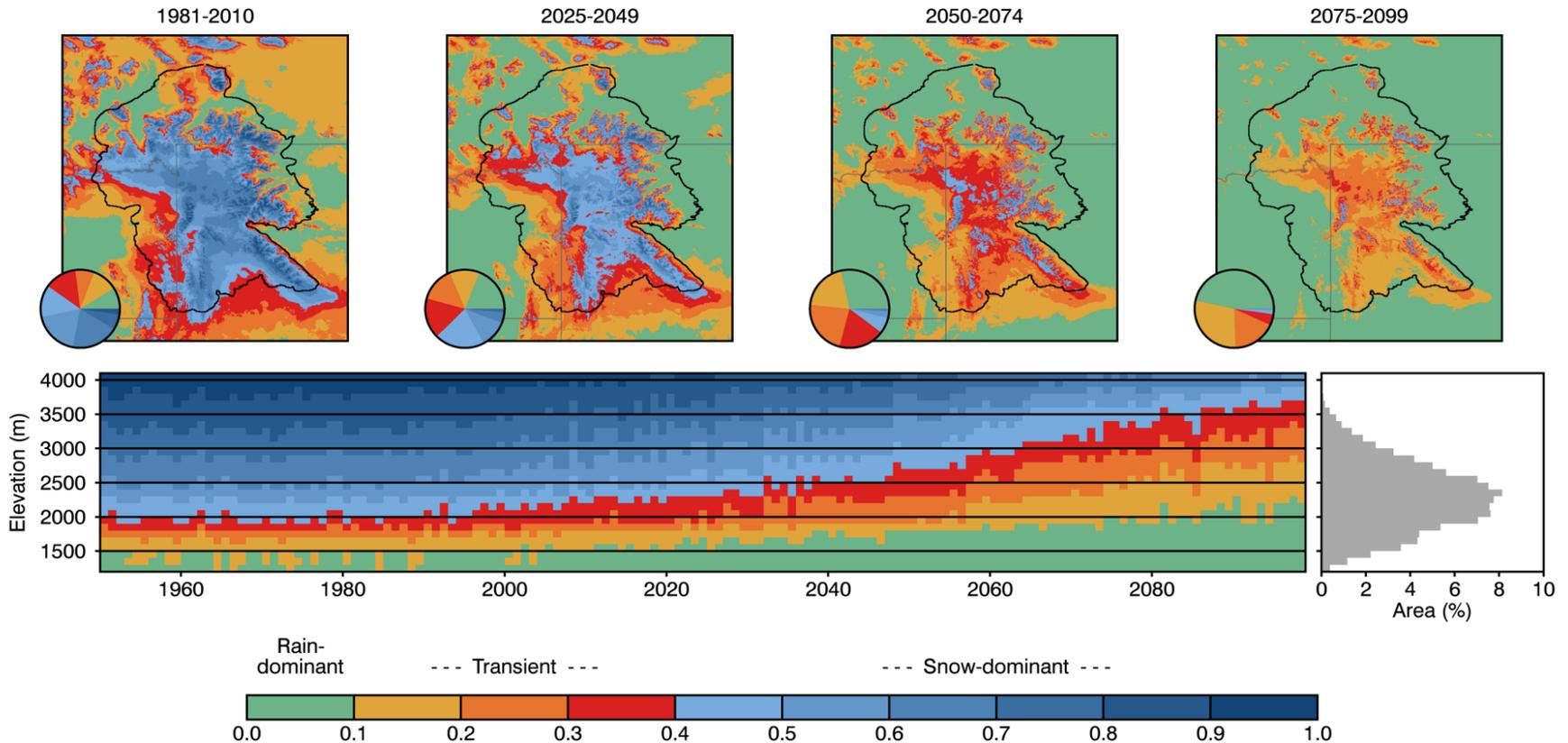
Loss of snow and snow covered areas

- 2050-2074 vs 1981-2010
 - GYE: -42% SWE, -27% SCA
 - UCB: -52% SWE, -20% SCA
 - SN: -47% SWE, -27% SCA
-
- Snow regimes
 - $SWE_{max} : \Sigma P_{(Oct-Apr)}$
 - Rain dominated (RD)
 - Transient (TR)
 - Snow dominated (SD)



Change in snow regime : GYE

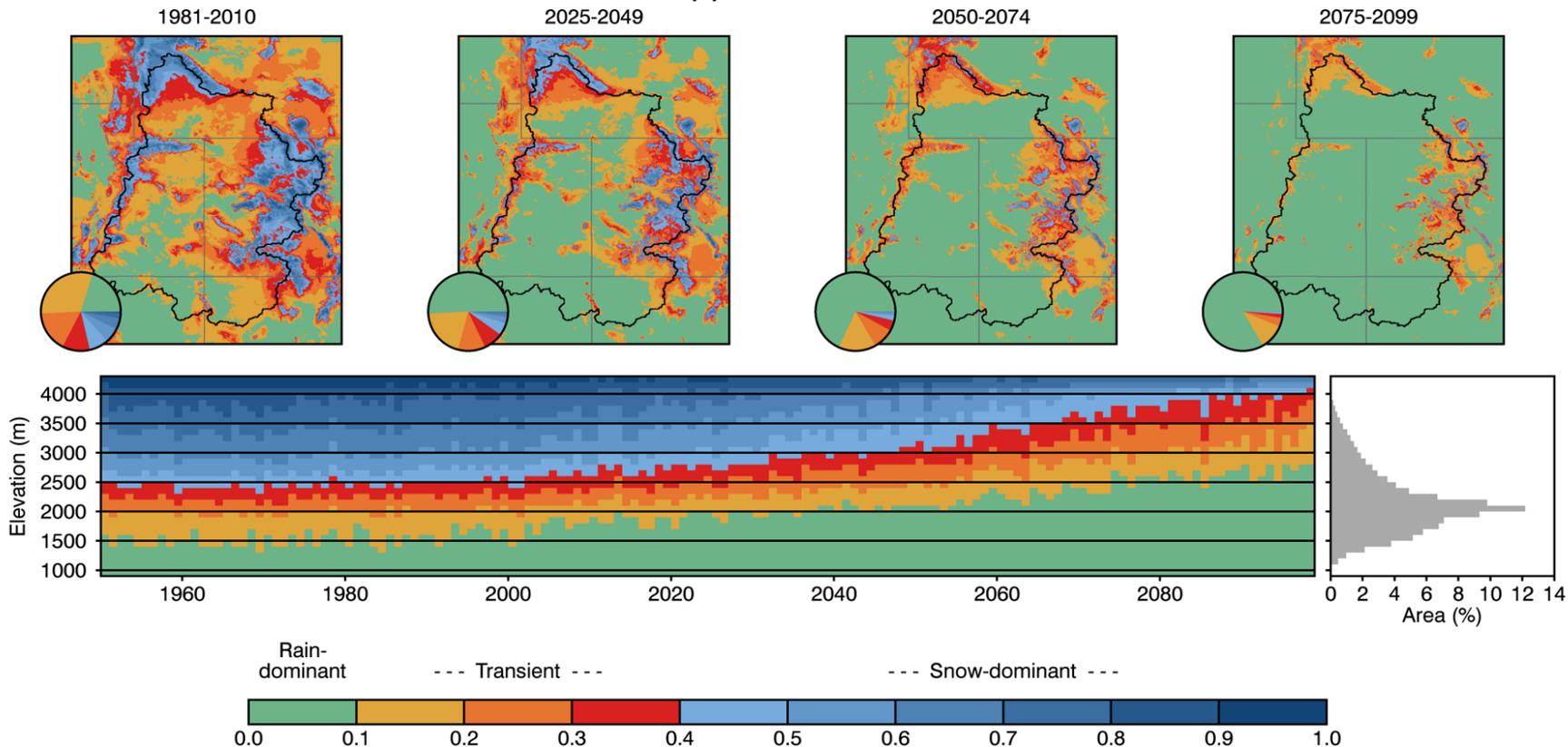
Greater Yellowstone Area



Ensemble mean

Change in snow regime : UCB

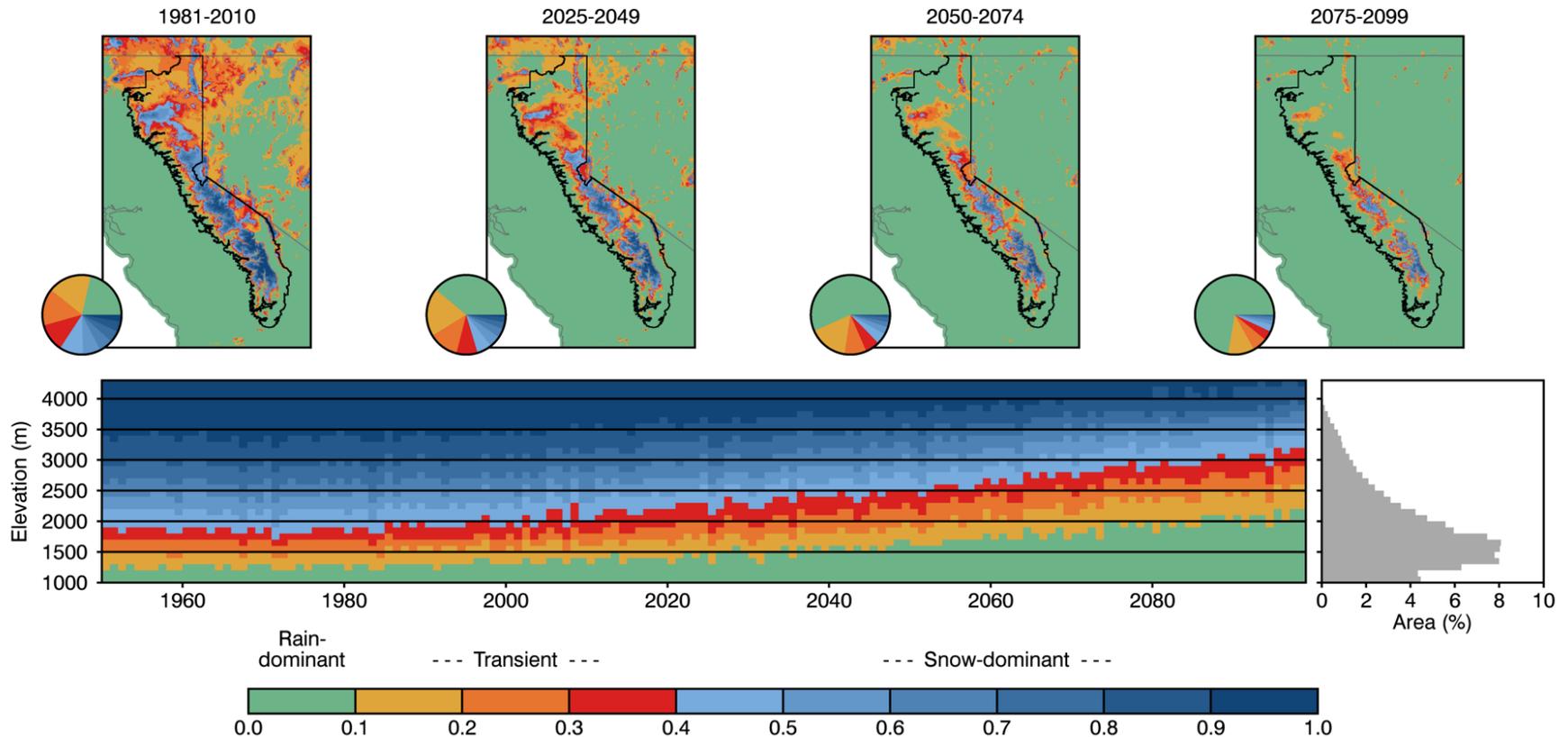
Upper Colorado



Ensemble mean

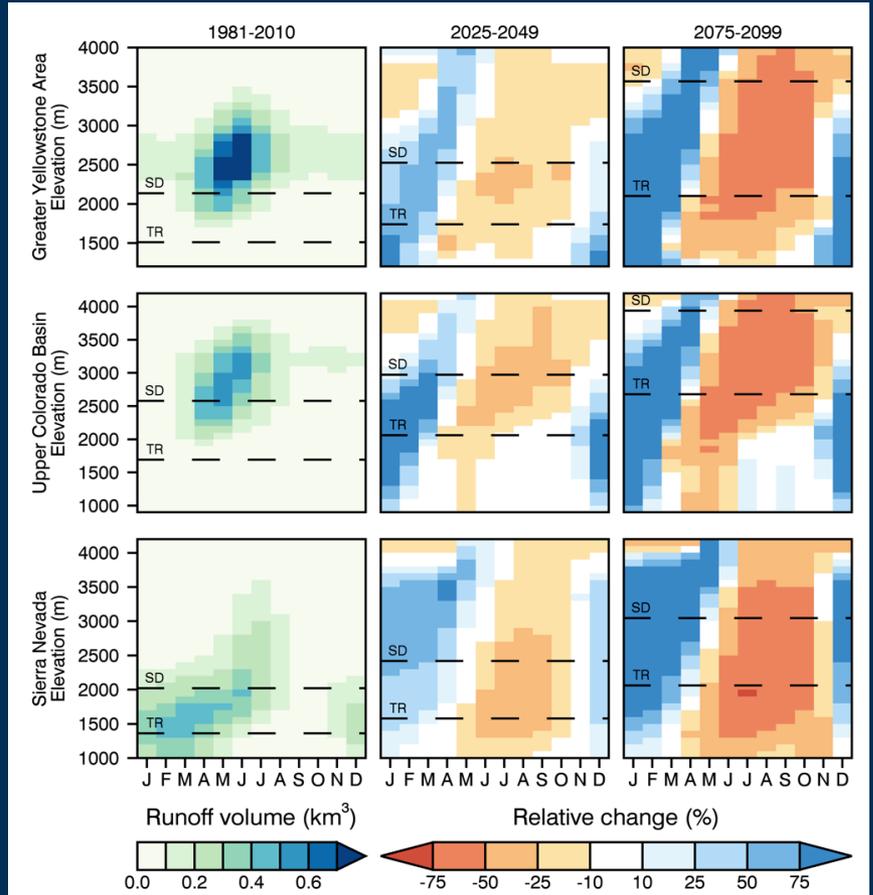
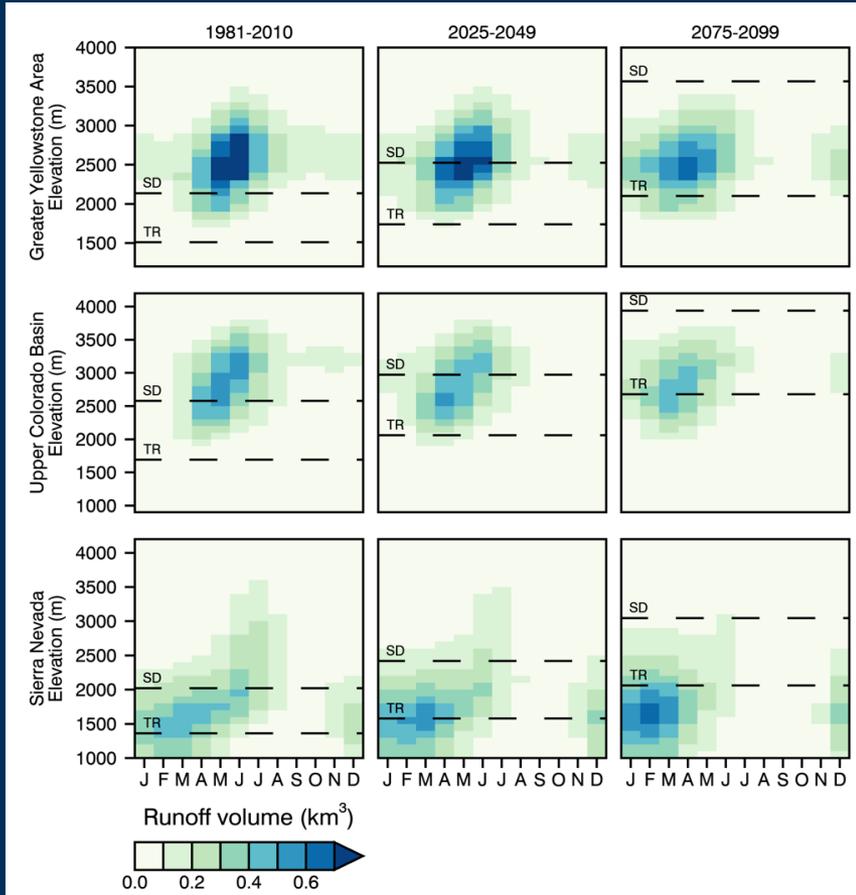
Change in snow regime : SN

Sierra Nevada



Ensemble mean

Seasonal changes in runoff volume by elevation

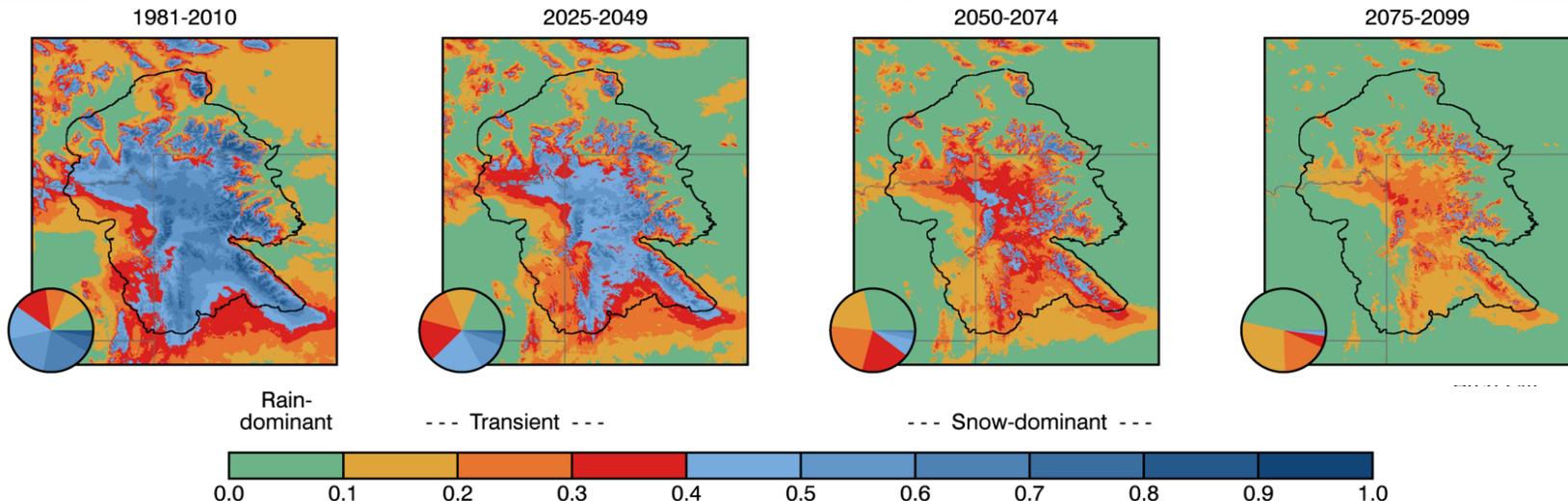


Ensemble mean



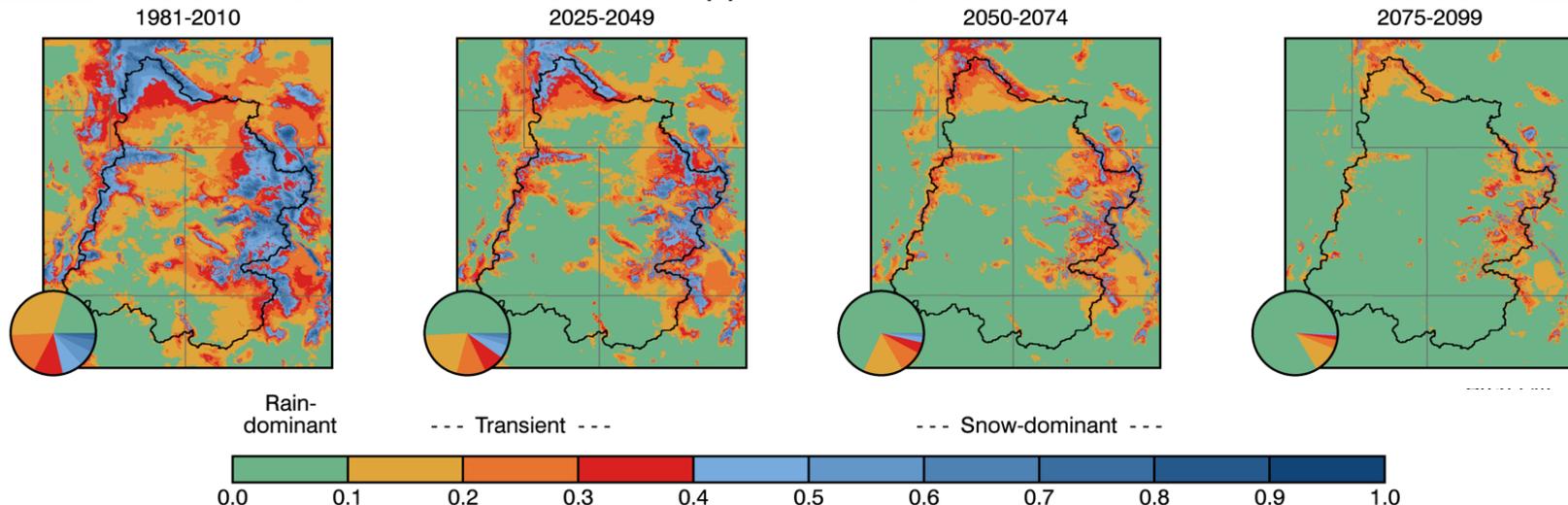
GYE: source contribution to annual total runoff

GYA	Rain			Snowmelt		
	RD (%)	TR (%)	SD (%)	RD (%)	TR (%)	SD (%)
1981-2010	4.3	16.1	34.9	0.6	6.9	37.1
2025-2049	9.8	26.0	26.1	1.4	12.5	24.2
2050-2074	16.0	43.2	9.0	2.3	21.6*	8.0
2075-2099	29.3	43.6	2.2	4.6	18.4	1.9



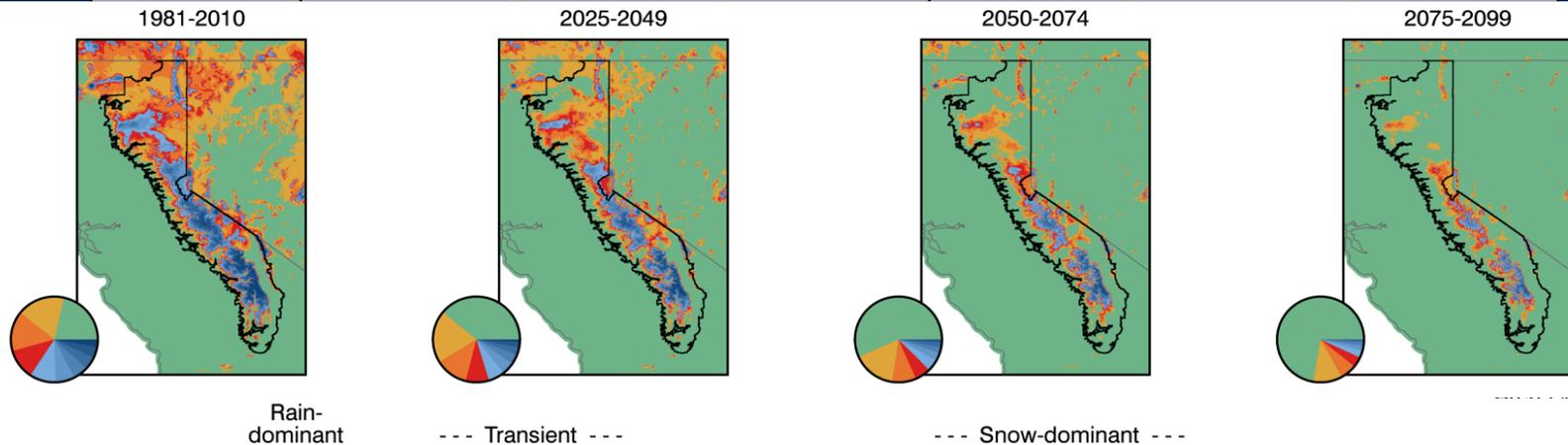
UCB: source contribution to annual total runoff

GYA	Rain			Snowmelt		
	RD (%)	TR (%)	SD (%)	RD (%)	TR (%)	SD (%)
1981-2010	9.6	36.9	19.7	1.8	13.3	18.7
2025-2049	28.8	32.7	11.1	4.7	12.7	10.0
2050-2074	43.7	29.8	4.9	6.0	11.5	4.1
2075-2099	62.5	20.4	1.5	7.0	7.4	1.2



SN: source contribution to annual total runoff

GYA	Rain			Snowmelt		
	RD (%)	TR (%)	SD (%)	RD (%)	TR (%)	SD (%)
1981-2010	16.0	24.1	13.0	2.8	15.0	29.0
2025-2049	29.4	24.8	8.7	4.4	14.8	17.8
2050-2074	42.7	22.5	5.8	5.4	12.8	10.9
2075-2099	58.6	17.2	3.3	5.9	9.4	5.6



High elevation (>3000m) changes

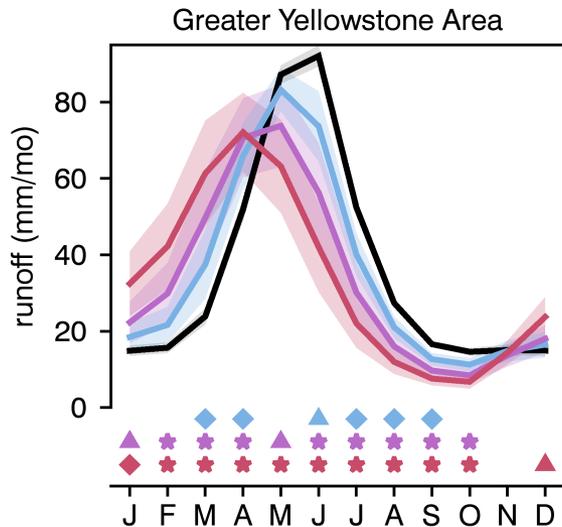
	March	Cold Season		
	SWE	Precip	Snowfall	Temp
GYE				
1981-2010	409 mm	599 mm	506 mm	-6.6 °C
2025-2049	-4.3%	+10.5%	-4.8%	+1.9 °C
2050-2074	-19.9%	+17.0%	-15.1%	+3.5 °C
2075-2099	-39.9%	+25.0%	-28.5%	+5.2 °C
UCB				
1981-2010	351 mm	552 mm	422 mm	-4.6 °C
2025-2049	-13.1%	+6.8%	-9.5%	+1.9 °C
2050-2074	-34.1%	+8.5%	-24.2%	+3.5 °C
2075-2099	-55.8%	+12.3%	-40.4%	+5.1 °C
SN				
1981-2010	641 mm	804 mm	744 mm	-2.9 °C
2025-2049	-5.6%	+4.1%	-3.8%	+1.5 °C
2050-2074	-17.7%	+2.8%	-13.8%	+2.9 °C
2075-2099	-31.9%	+3.4%	-25.3%	+4.3 °C

7.9% of the region is high elevation

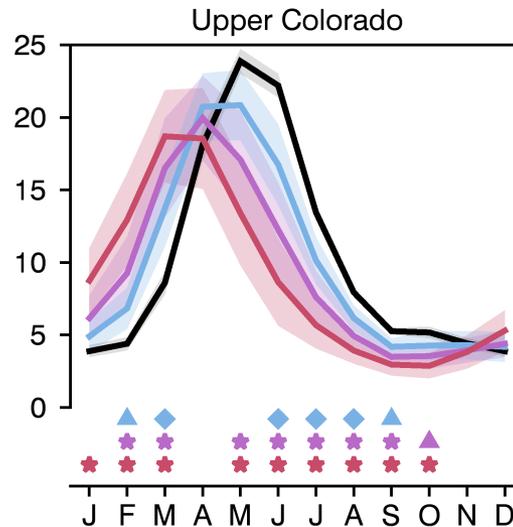
7.7% of the region is high elevation

6.3% of the region is high elevation

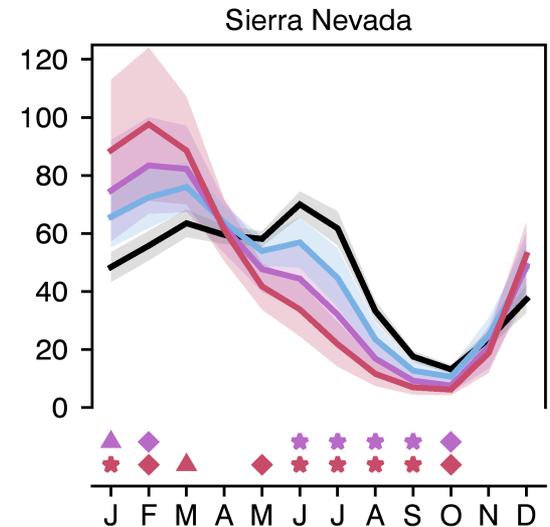
Changes in runoff timing



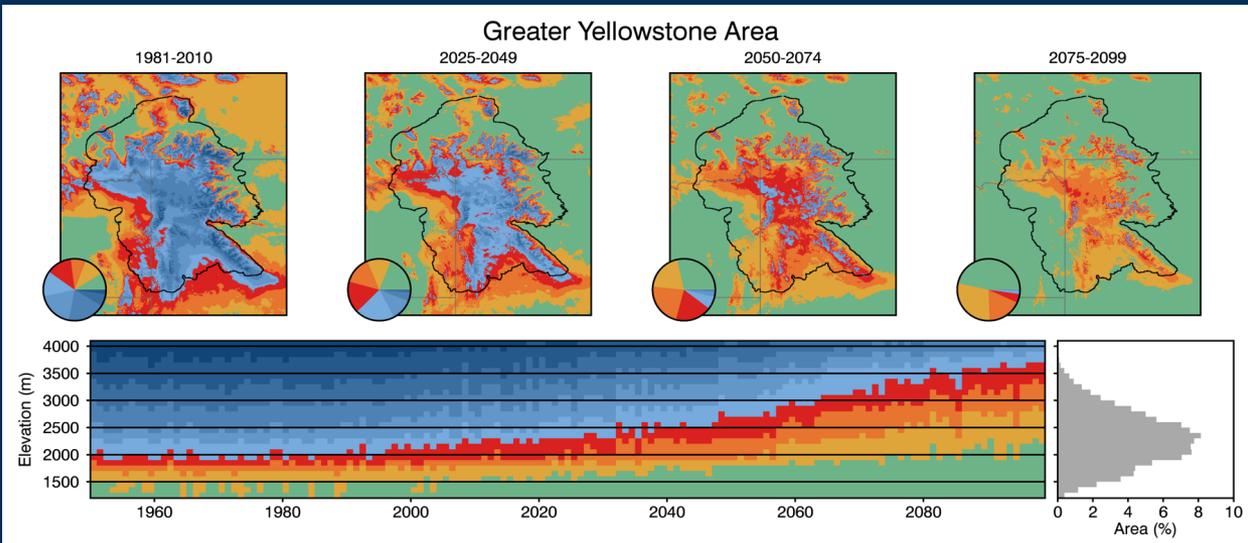
— 1981-2010
 — 2025-2049
 — 2050-2074
 — 2075-2099



▲ 55-70% of model changes are significant and in agreement
 ◆ 70-85% of model changes are significant and in agreement
 ★ 85-100% of model changes are significant and in agreement

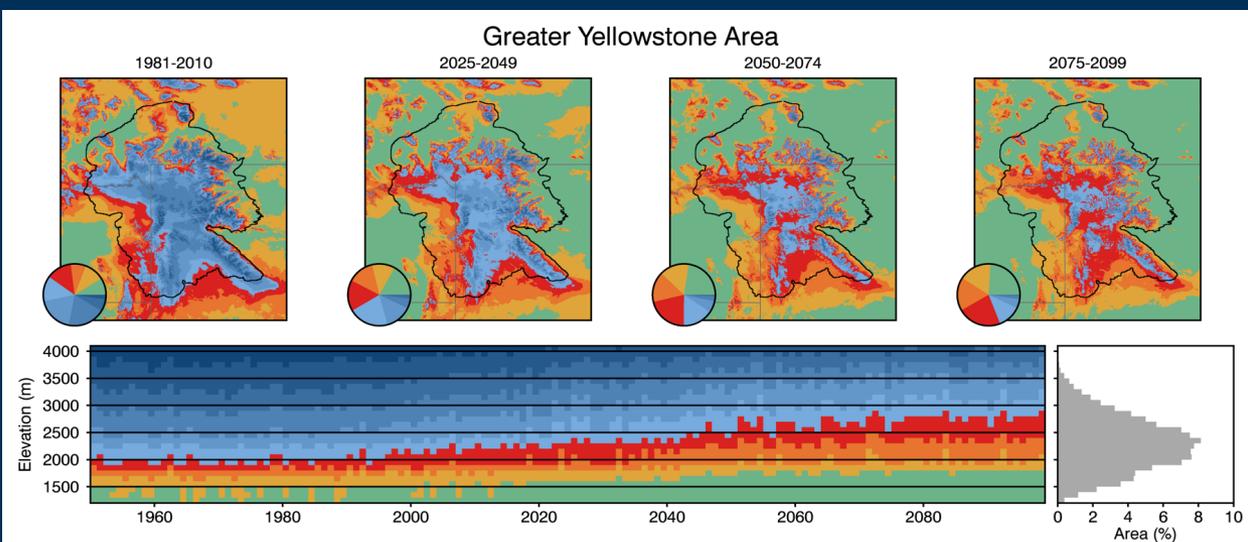


RCP8.5 vs RCP4.5



RCP8.5

	SD area (%)	SD elev (m)	Δ SWE (%)	Δ SCA (%)
2050-2074	10	3022	-42	-27
2075-2099	2	3567	-64	-42



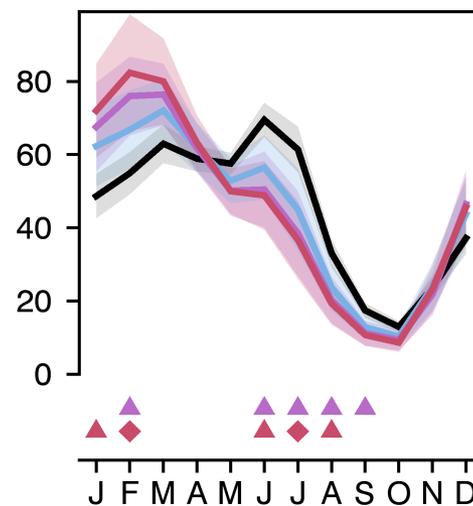
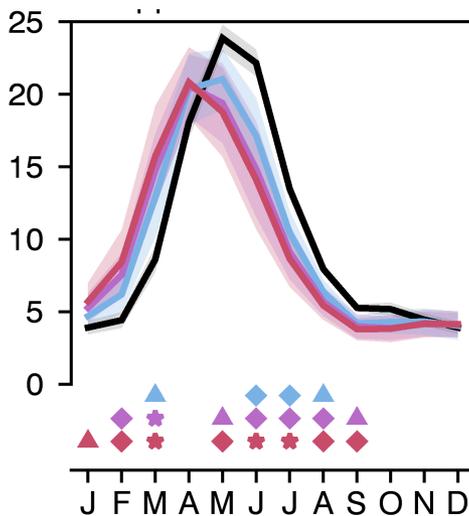
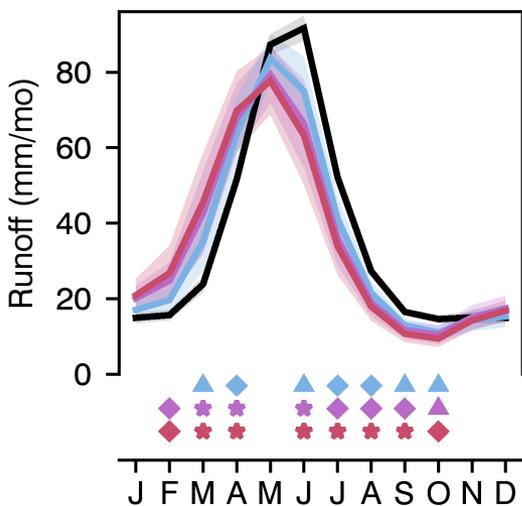
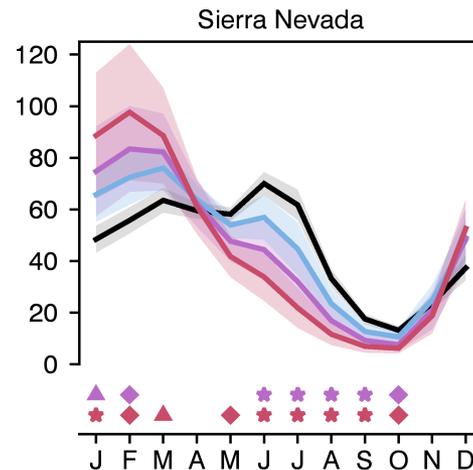
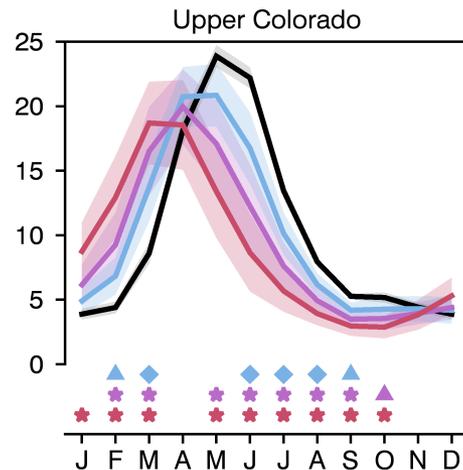
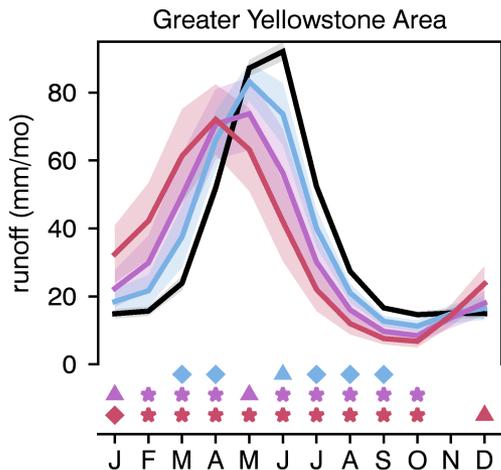
RCP4.5

	SD area (%)	SD elev (m)	Δ SWE (%)	Δ SCA (%)
2050-2074	25	2710	-29	-18
2075-2099	19	2833	-33	-21

RCP8.5 vs RCP4.5

RCP8.5

RCP4.5



— 1981-2010
 — 2025-2049
 — 2050-2074
 — 2075-2099

▲ 55-70% of model changes are significant and in agreement
 ◆ 70-85% of model changes are significant and in agreement
 ★ 85-100% of model changes are significant and in agreement



Summary

- Despite uncertainty in precipitation projections, temperature driven changes in hydroclimate have strong model agreement with significance.
- By the end of the 21st Century, only the highest elevations remain snow dominated, where transient and rain dominated zones greatly expand.
- The reduced storage in snow pack advances the seasonal timing of runoff.