

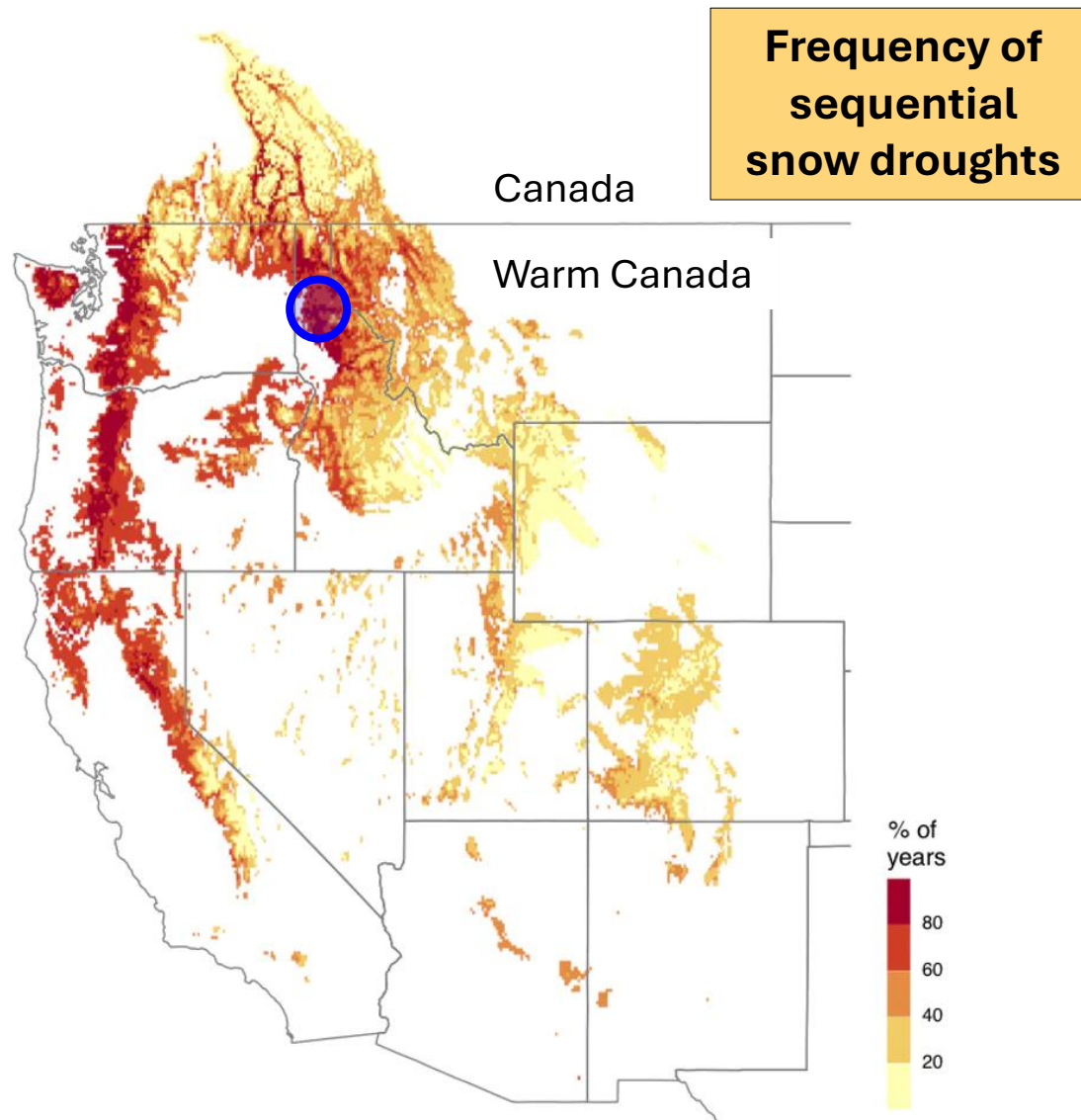
Challenges in defining “effectively no snow”

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COLORADO SCHOOL OF
MINES

University of Idaho



Motivation:

- Many mountain regions are transitioning from snow to rain
- Frequency of snow droughts are increasing
- How to define when a point has ***effectively no snow?***
- How to define when a catchment has ***effectively no snow?***

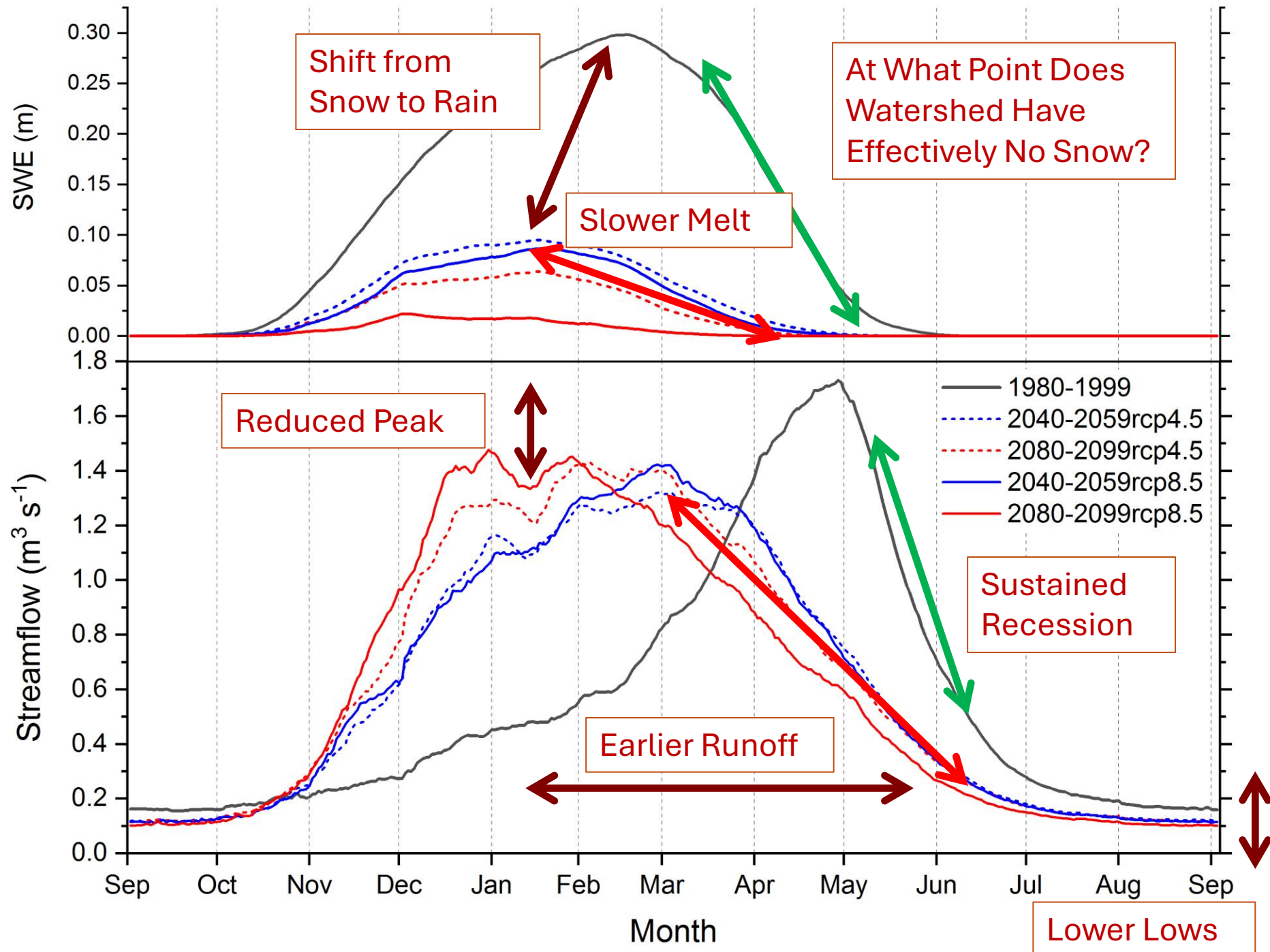
Marshall, A. M., J. T. Abatzoglou, T. E. Link, and C. Tennant. 2019. Projected changes in interannual variability of peak snowpack amount and timing in the western United States. *Geophysical Research Letters*, 46(15), 8882-8892. <https://doi.org/10.1029/2019GL083770>.

Mica Creek Experimental Watershed

Northern Idaho

Projected Snow and Streamflow

10 GCM ensemble
DHSVM simulation



Other Consequences of Snow Drought

- Example: North Cascades, WA
- 2026 warm snow drought
- $<10^{\text{th}}$ percentile peak SWE
- Early drying of large fuels
- Snow was still 50-60% median peak SWE
- Low snow, but not no snow.



Coxit Mountain East INARCH Watershed



A low-to-no snow future and its impacts on water resources in the western United States

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Abstract | Anthropogenic climate change is decreasing seasonal snowpacks globally, with potentially catastrophic consequences on water resources, given the long-held reliance on snowpack in water management. In this Review, we examine the changes and trickle-down impacts of snow loss in the western United States (WUS). Across the WUS, snow water equivalent declines of ~25% are expected by 2050, with losses comparable with contemporary historical trends. There is less consensus on the time horizon of snow disappearance, but model projections combined with a new low-to-no snow definition suggest ~35–60 years before low-to-no snow becomes persistent if greenhouse gas emissions continue unabated. Diminished and more ephemeral snowpacks that melt earlier will alter groundwater and streamflow dynamics. The direction of these changes are difficult to constrain given competing factors such as higher evapotranspiration, altered vegetation composition and changes in wildfire behaviour in a warmer world. These changes undermine conventional WUS water management practices, but through proactive implementation of soft and hard adaptation strategies, there is potential to build resilience to extreme, episodic and, eventually, persistent low-to-no snow conditions. Federal investments offer a timely opportunity to address these vulnerabilities, but they require a concerted portfolio of activities that cross historically siloed physical and disciplinary boundaries.

Mountains are known as the water towers of the world, capturing, storing and releasing water for downstream use^{1,2}. In the western United States (WUS), as in many global regions³, this natural service largely occurs through seasonal mountain snowpacks (FIG. 1a), storing approximately 200 km³ or 162 million acre-feet (MAF) of water annually^{4,5}, as quantified through snow water equivalent (SWE). In places such as California, for example, average 1 April snowpack water storage (21 km³ or 17 MAF) nearly doubles the amount of surface water reservoir storage (29 km³ or 23.5 MAF)⁶. The springtime and summertime melt of these seasonal snowpacks is fundamental to water infrastructure and operations, supplying water during times of precipitation scarcity and when agricultural, ecological and municipal water demands are high⁶. Over the last century, observations and models reveal that anthropogenic climate change has substantially reshaped WUS water resources, including a declining snowpack^{7–9,10–17}. For instance, observed 1 April snowpack decline since the mid-twentieth century ranged between 15 and 30% or 25 and 50 km³ (REF.¹⁸).

Future mountain snowpacks are further projected to decline, and even disappear, but at unknown rates⁴. While the complete loss of snow is the worst-case scenario, a plausible situation informed by estimates of historical low-snow conditions (FIG. 1b) would be a WUS-wide reduction in SWE and seasonal snow, and a shift from rare or short-term to more persistent low-to-no snow occurrences.

The potential for persistent low-to-no snow to disrupt the WUS water system is substantial, potentially even catastrophic. Water storage and conveyance infrastructure was designed and is now managed using spring snowmelt as a central criterion for operations^{19–22}. These water management decisions are predicated on the assumption of a stationary climate^{19,23}, which is an unintended, yet, critical, oversight. Moreover, water rights allocations for many major WUS rivers were made in the late nineteenth and early twentieth century at the end of the Little Ice Age (AD 1400–1900)^{24–26}, a period that is among the wettest in the past 4,000 years^{27–32}. Given the high confidence that continued warming will result in

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Point Scale: One Definition of “(Effectively) No Snow”

“...peak SWE conditions within the lowest 10th percentile”.

- Siirila-Woodburn et al., 2021

The Concern:

“(Effectively) no snow”

...assumes locations have effectively no snow at lowest 10% of years

Does not match colloquial or scientific understandings of “(effectively) no snow”

Correspondence Intention:
Correct fallacious definition

Correspondence

<https://doi.org/10.1038/s43017-026-00819-6>

The challenge of defining effectively no snow

 Check for updates

Siirila-Woodburn et al. define snowpack conditions based on percentiles of historical snow water equivalent (SWE)¹. Specifically, ‘low snow’ is defined as “conditions in which peak SWE falls between the 30th and 10th percentiles”, and ‘effectively no snow’ is defined as “peak SWE conditions within the lowest 10th percentile”. This definition of ‘low-to-no-snow’ conditions is described as an important metric to help stakeholders in snow-dependent systems develop proactive adaptation strategies for water resources and ecosystem management. As applied in Siirila-Woodburn et al., the ‘effectively no snow’ definition presupposes that over the historical range of variability (HRV), each location has effectively no snow at its lowest 10% of years. However, in much of the western United States (WUS), this definition is unlikely to match colloquial or scientific understandings of ‘effectively no snow’, as observations meeting this criterion

could be snow-covered, with sufficient SWE to contribute meaningfully to water resources.

At locations with low HRV, the 10th percentile peak SWE value can be close to the mean and/or median value. At SNOTEL and California Department of Water Resources snow pillows² with at least 30 years of data, the 10th percentile peak SWE value averages 0.3 ± 0.2 m ($\pm$ std. dev.) (Fig. 1a), equivalent to $64 \pm 12\%$ of the median value (Fig. 1b). The 10th percentile ranges from 21–85% of median peak SWE, and it is lower in the maritime WUS than in the intermountain and Rocky Mountain regions (Fig. 1). These differences likely arise from lower HRV in these mountain regions³ driven by a combination of cool temperatures and low interannual variability of winter precipitation⁴. Therefore, the definition used in Siirila-Woodburn et al. is likely more appropriate for the warmer, higher variability snowpacks of California, Oregon, and southwestern mountains than the cooler interior WUS.

These definitional issues do not change the projections of dire snow losses described in Siirila-Woodburn et al., which are highly consequential to water resources and ecosystems throughout the WUS. However, care should be taken with the terms ‘effectively no snow’ and ‘low-to-no snow’ to ensure that the scientific community and stakeholders have a clear understanding of actual projected changes in peak SWE historical percentiles and SWE amounts. Specifically, definitions that can retain meaningful SWE, such as the 10th percentile, should be avoided in the identification of ‘effectively no snow’ conditions.

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2. Marshall, A. M., Abatzoglou, J. T., Rahimi, S., Lettenmaier, D. P. & Hall, A. California’s 2023 snow deluge: contextualizing an extreme snow year against future climate change. *Proc. Natl Acad. Sci. USA* **121**, e2320600121 (2024).
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Competing interests

The authors declare no competing interests.

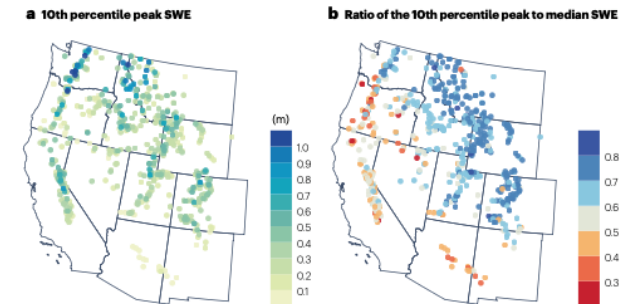
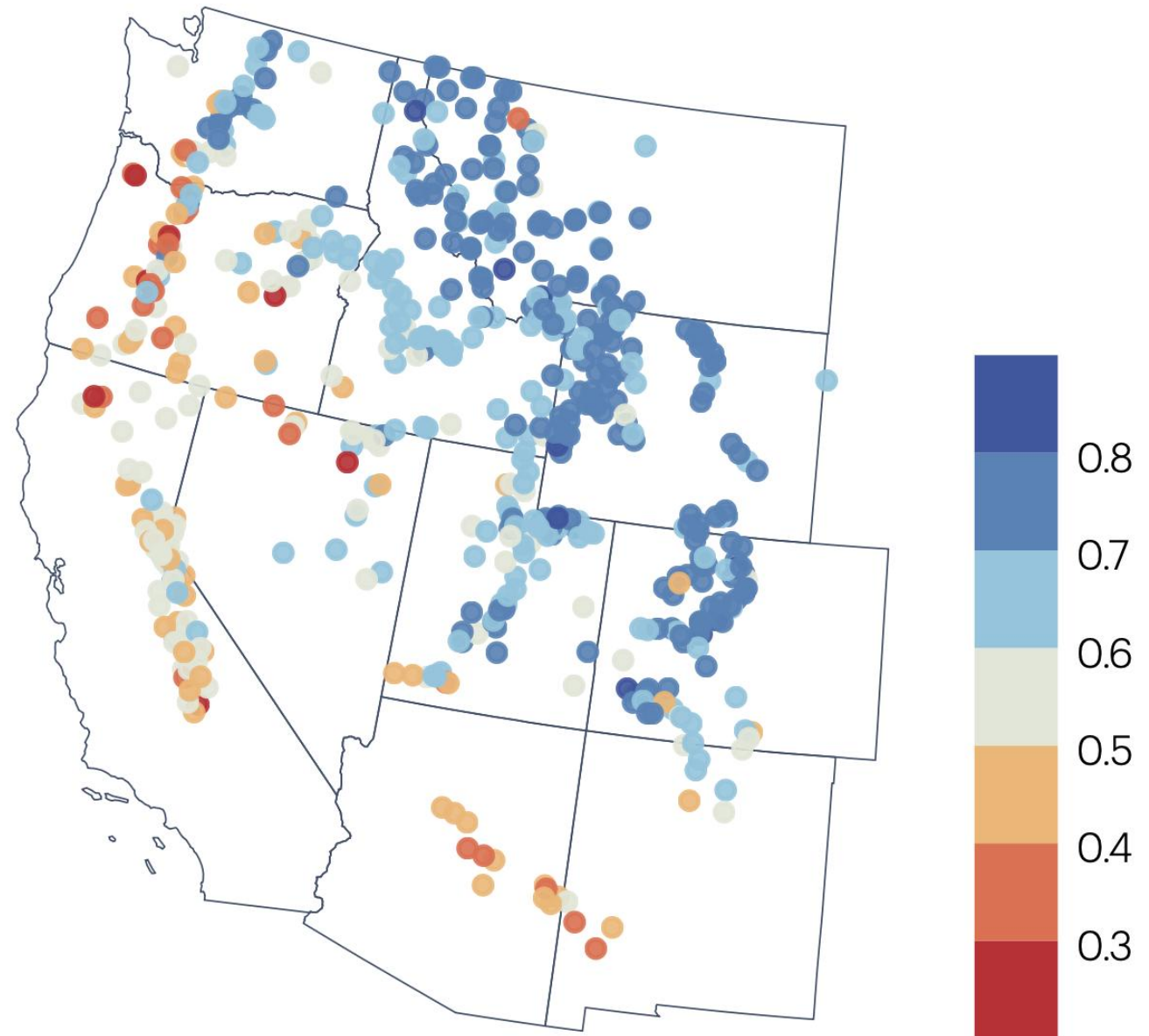


Fig. 1 | The 10th percentile of snow water equivalent (SWE) across the western United States. a. The 10th percentile peak SWE value (m). **b.** The ratio of 10th percentile peak SWE to median peak SWE over the full period of record for each site. Data from ref. 2. The 10th percentile of peak SWE can represent meaningful snow volumes that do not equate to ‘effectively no snow’.

Ratio of the 10th percentile peak to median SWE

SNOTEL and CADWR Observations ≥ 30 years

- Interior Mountains:
Lower historical range
of variability
 - Cooler
 - Lower interannual
winter precipitation
variability



Marshall, A. M., & Link, T. E. (2026). The challenge of defining effectively no snow. *Nature Reviews Earth & Environment*, 0. <https://doi.org/10.1038/s43017-026-00819-6>

SNOTEL and CADWR Observations ≥ 30 years

Across western US:

10th percentile median peak SWE

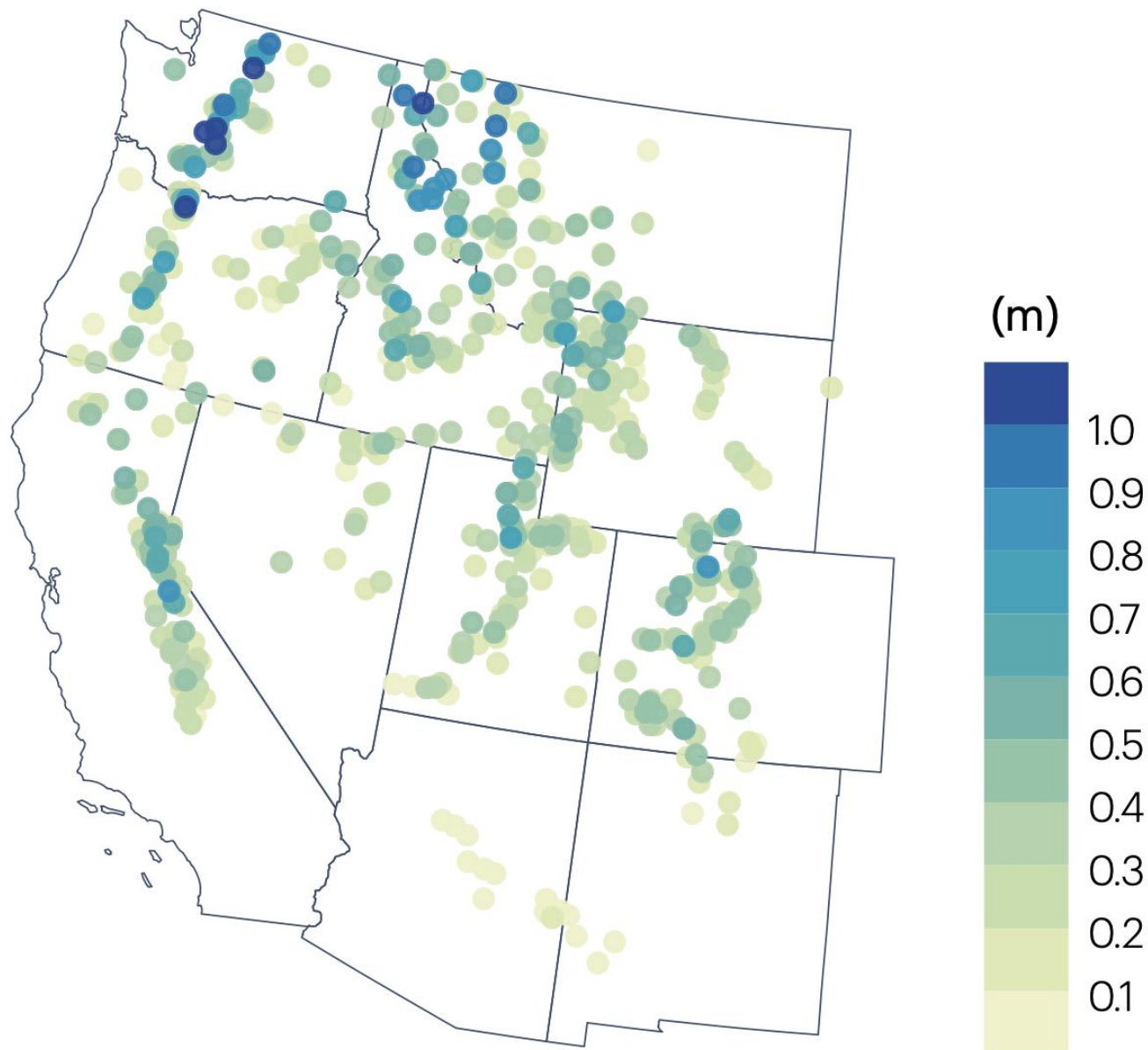
- **Mean: 30 ± 20 cm (StDev)**
- **$64 \pm 20\%$ median peak SWE**

Depth $\approx 30\text{cm}/\sim 0.4 \approx 75$ cm

Depth $\approx 50\text{cm}/\sim 0.4 \approx 125$ cm

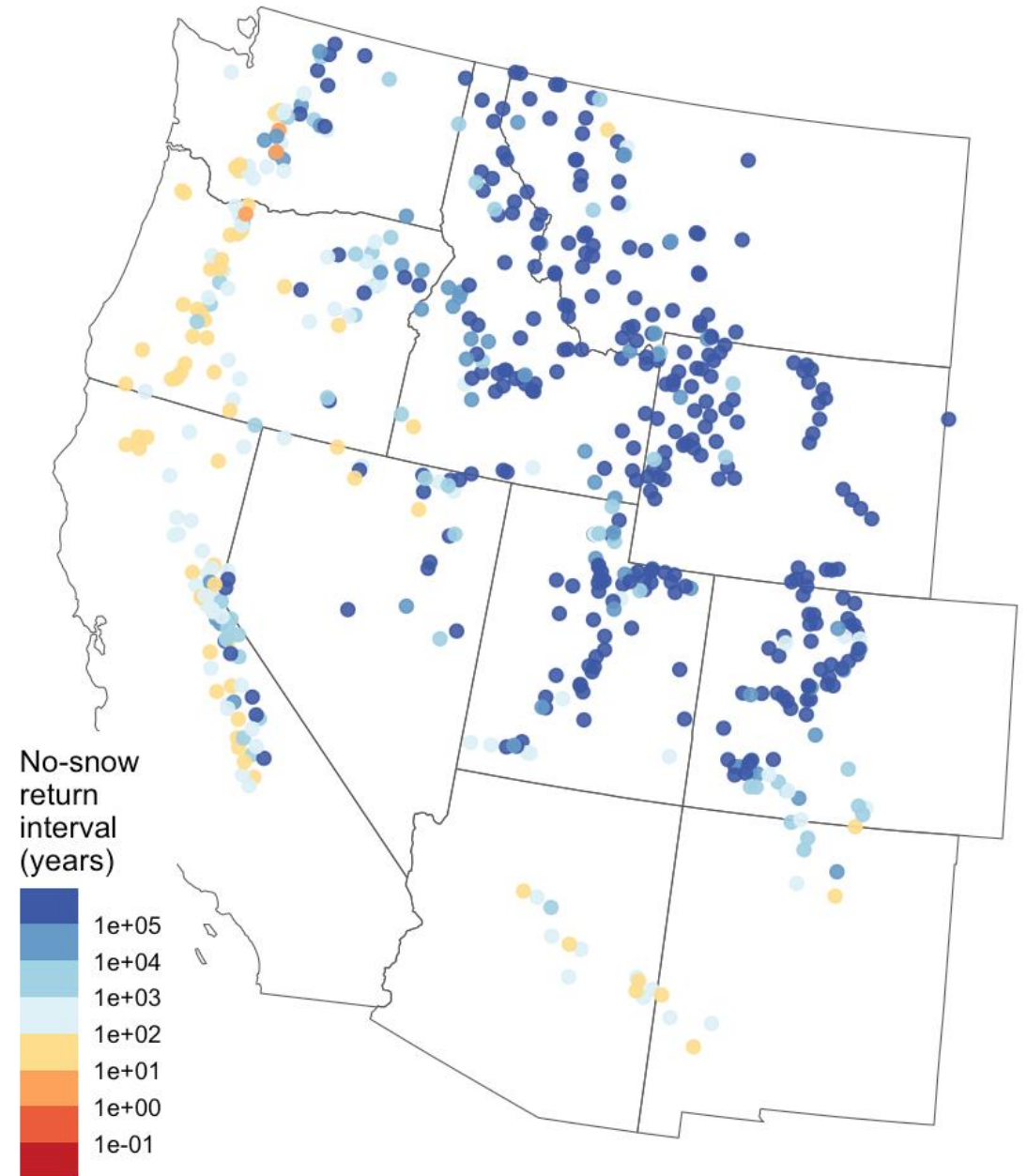
Mean ≈ 2.5 ft; Upper SD $\approx >4$ ft

10th percentile peak SWE



Return Interval of (Effectively) No Snow:

If definition is based on
<10% median peak SWE



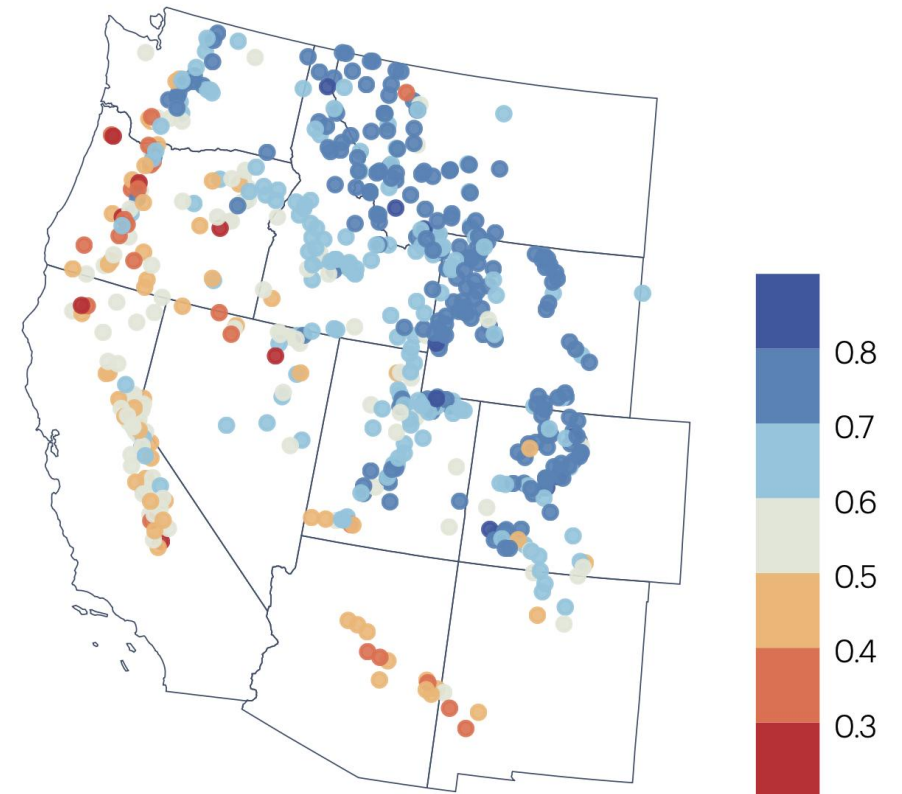
Summary: “Effectively No Snow”

At Point Scales...

- Lowest 10th percentile definition is appropriate *specifically* for:
 - WUS: California, Oregon, and SW Mountains
 - Warm, high variability snowpacks
- Definition is *not* appropriate for:
 - WUS: Rocky Mountain and intermountain regions
 - Cooler, low variability snowpacks

“Effectively no snow” should *probably* be based on % of median SWE

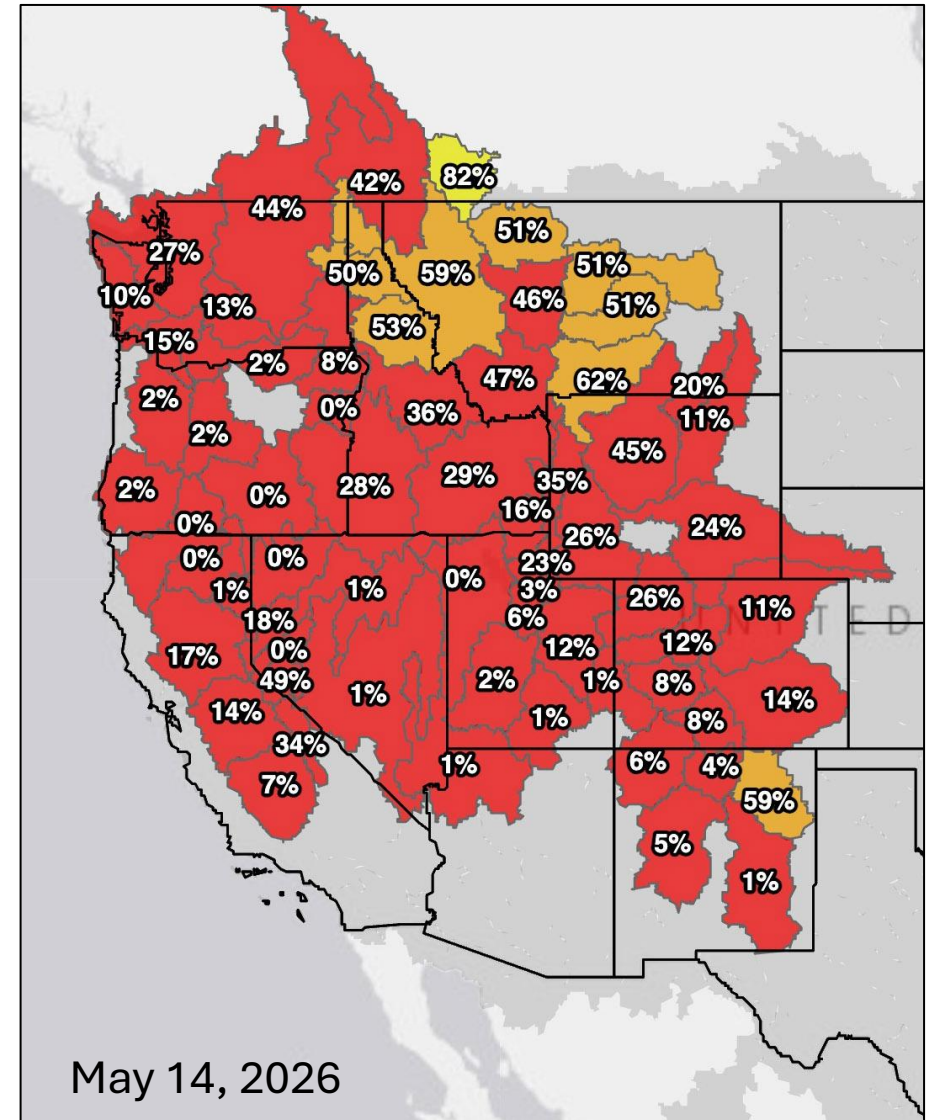
Ratio of the 10th percentile peak to median SWE



Summary: “Low Snow”

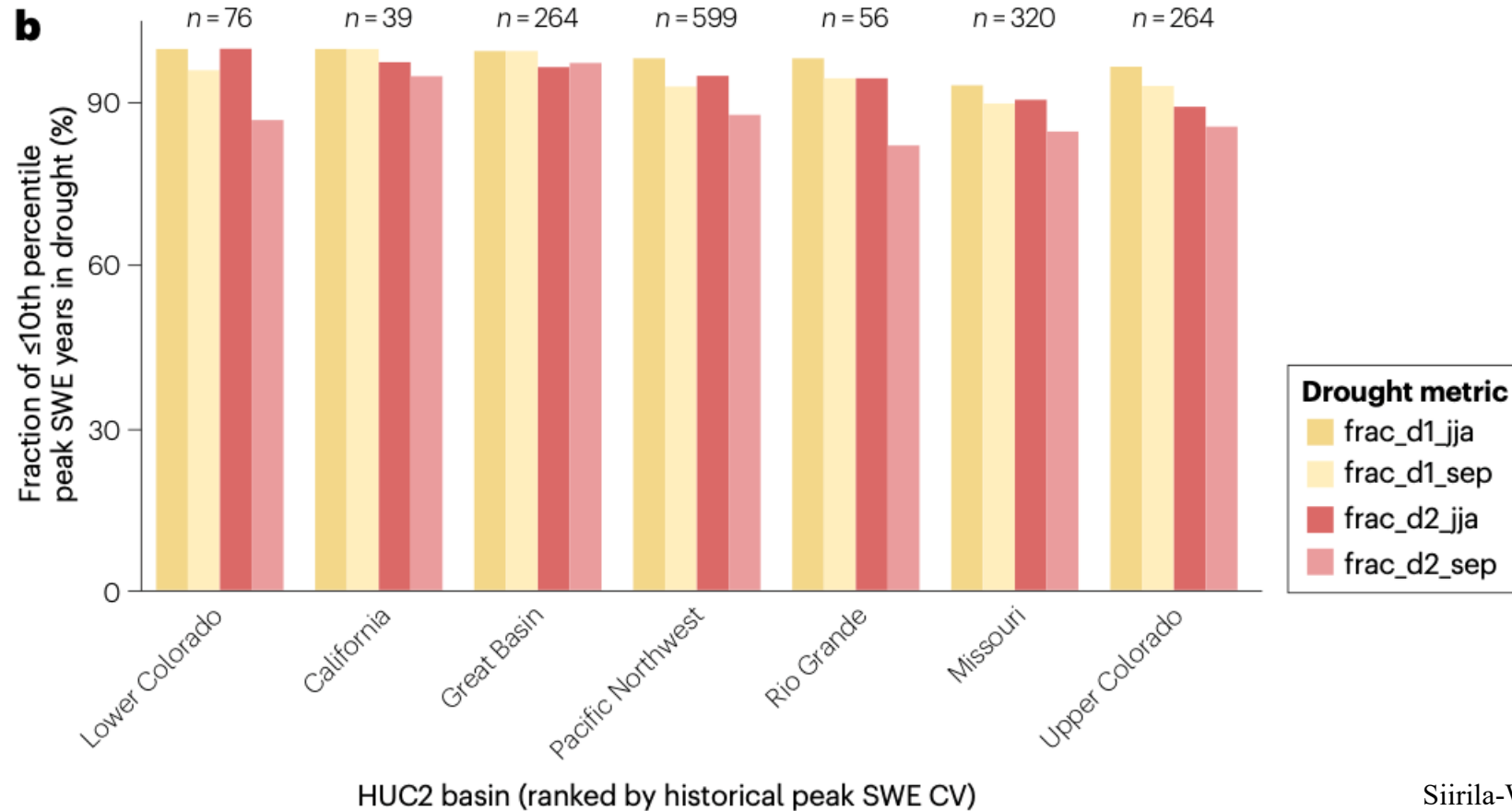
At Point Scales...

- Captured by lowest 10th and 30th percentiles (Siirila-Woodburn et al., 2021)
 - Good reference within the historical range of variability (HRV)
- **“Effectively no snow” should be based on % of median SWE**
 - Water resources projections are based on % median peak SWE →



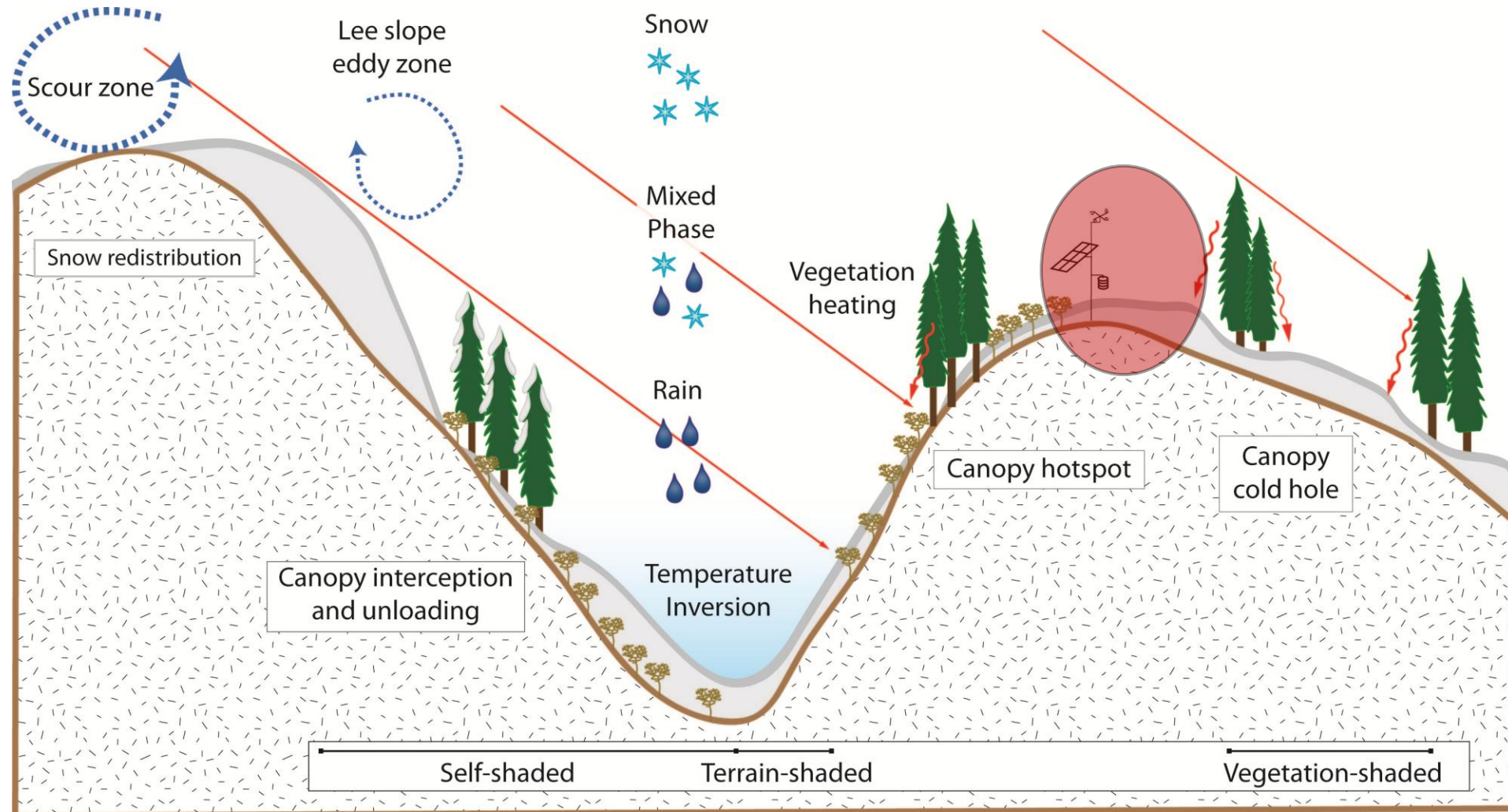
Large Scales: 10th Percentile Peak SWE and Drought

Moderate (d1) and Severe (d2)



- 10th Percentile is a useful metric for low snow
- **Large basins:** Lots of lower elevation contributing area
- **Small basins:** Still useful?

Mountain Hydrology Process Complexity



Questions and Challenges

When Does a Watershed Transition to Effectively No Snow?

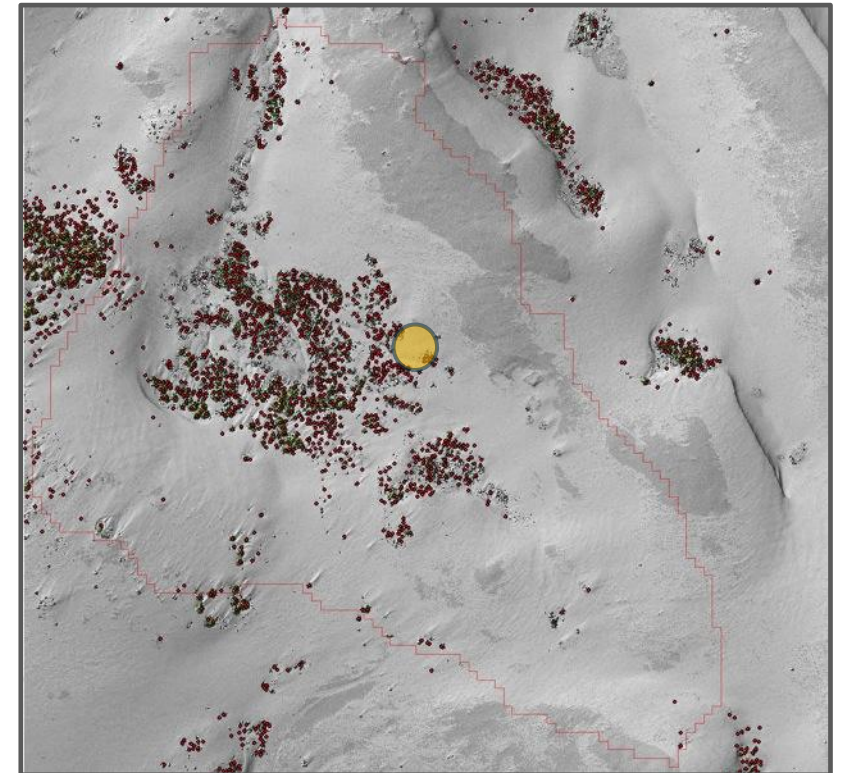
- Can a $<10^{\text{th}}$ percentile observation have meaningful water resources?
- Can a $<10^{\text{th}}$ percentile observation with higher SWE be effectively no snow?

Depends on specific questions, watersheds, and observations

- Probably unique to every watershed!

Possible INARCH Contributions:

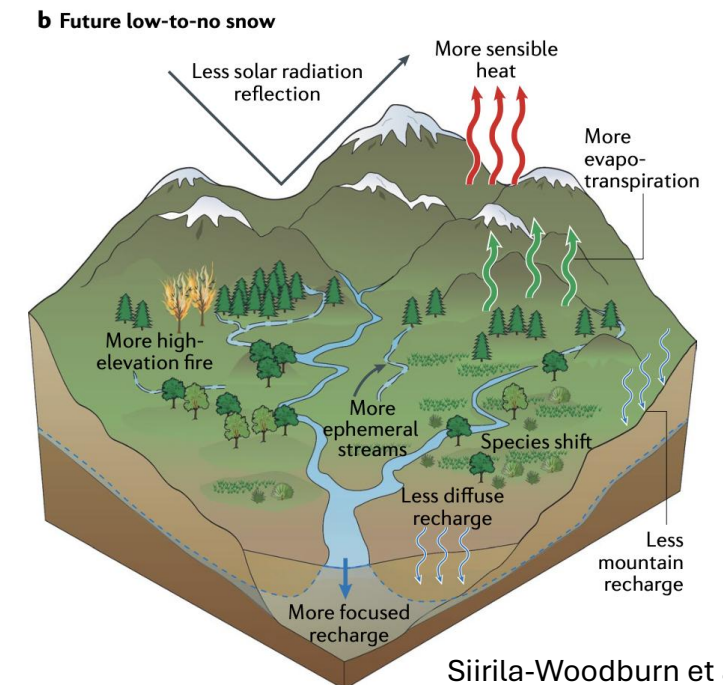
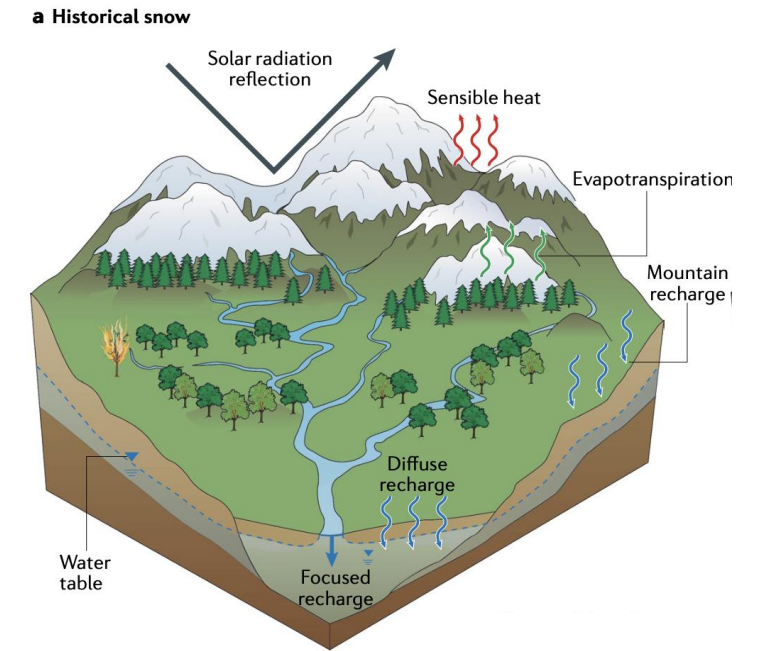
- Observational strategies to monitor hydrological regime transitions ahead
- Modeling approaches to help predict critical regimes changes



Reynolds Mountain East Watershed

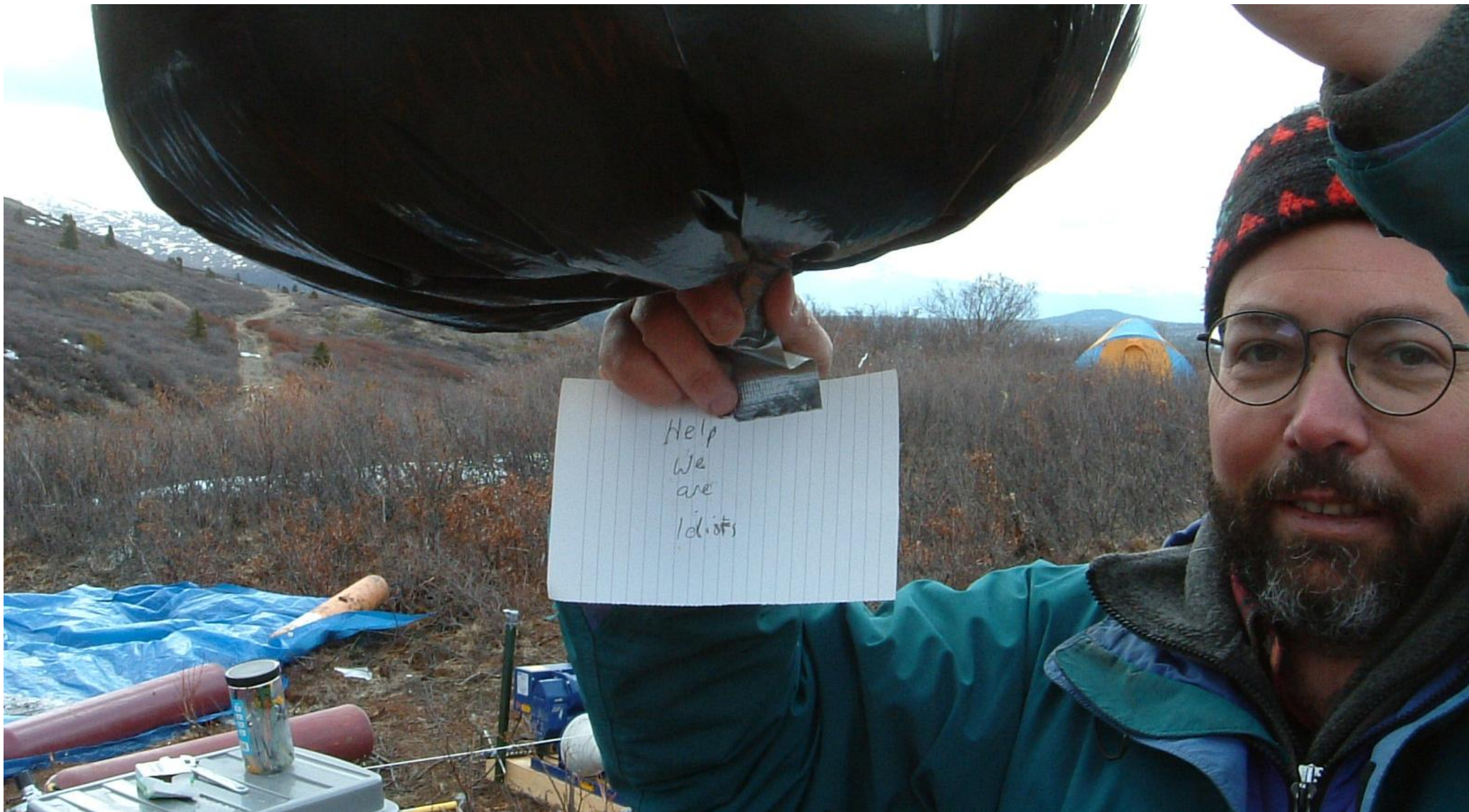
In Summary:

- 10th percentile of peak SWE should not be used to define “effectively no snow”
 - 64% median peak SWE across western US
- Percent of median peak SWE more appropriate
- “Effectively no snow” threshold will vary by watershed
 - Uses (e.g. agriculture, hydropower)
 - Interdisciplinary problem to address
- Addressing process uncertainty is key
- Peak SWE Percentile and Percent of Peak SWE confusing!



Words of Wisdom...

Help
We
are
Idiots



Help
We
are
Idiots



Thank You!

Questions?

