Climate change-resilient snowpack estimation with machine learning

17 October, 2024
ELLIIT Focus Period, Linköping University

Marianne Cowherd + many others
Including Utkarsh Mital, Stefan Rahimi, Andrew Schwartz, Lucas Vargas Zeppettello, Ruby Leung, Manuela Girotto, and Dan Feldman

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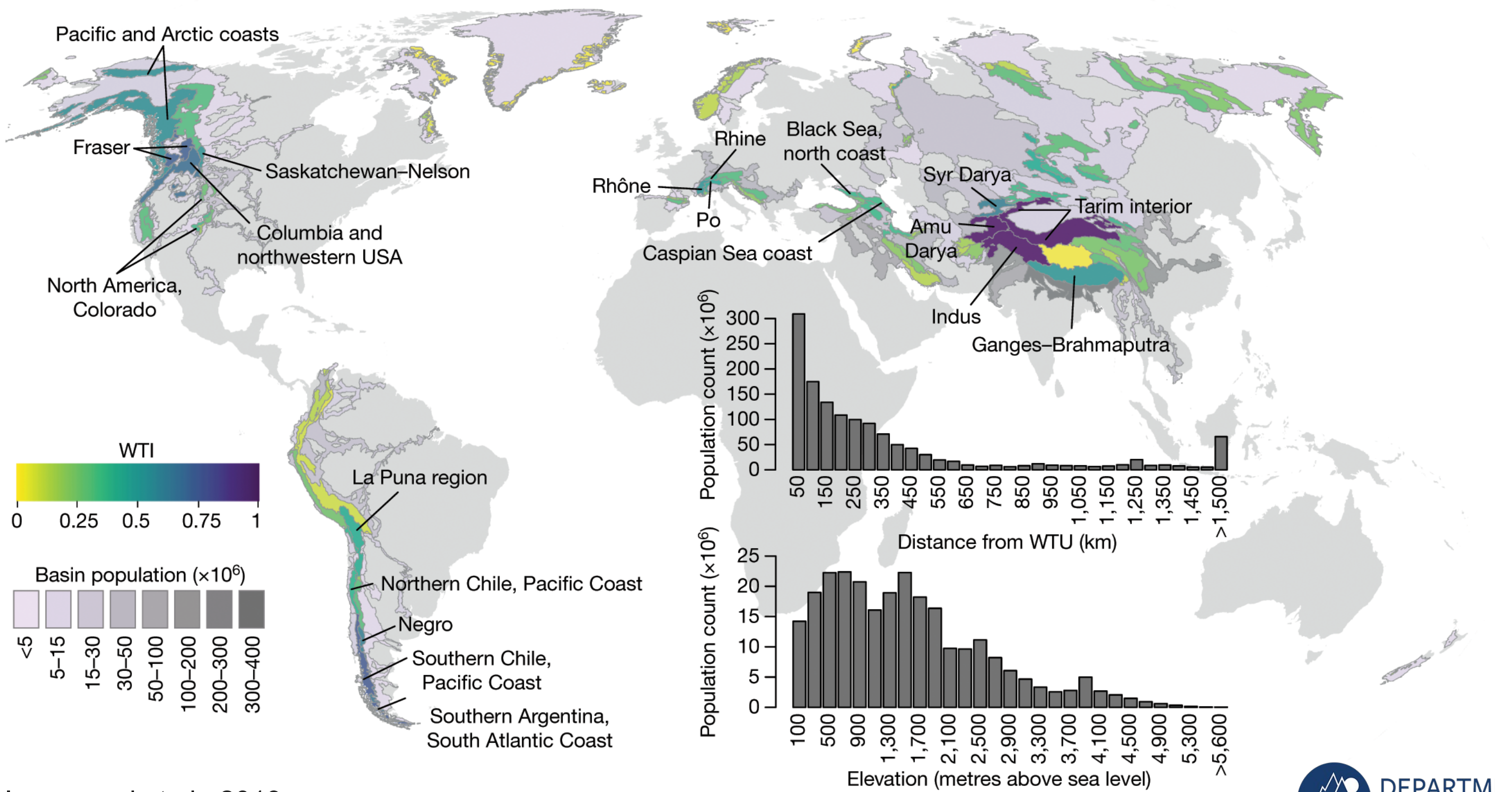
The domain science perspective:



Immerzeel et al., 2019

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We only manage snow as well as we measure it.

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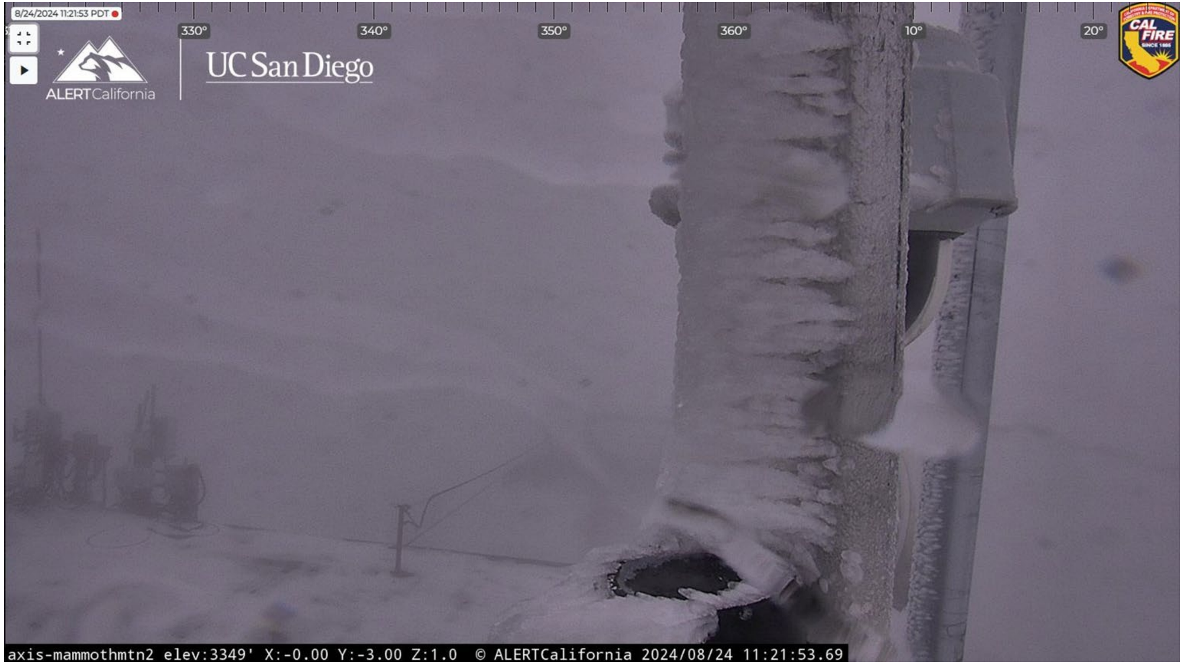
NEWS

Unusually Early Cold Storm Dusts Sierra Nevada Peaks With Rare August Snow

By The Associated Press Aug 24 Save Article



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How is snow measurement impacted by climate change?

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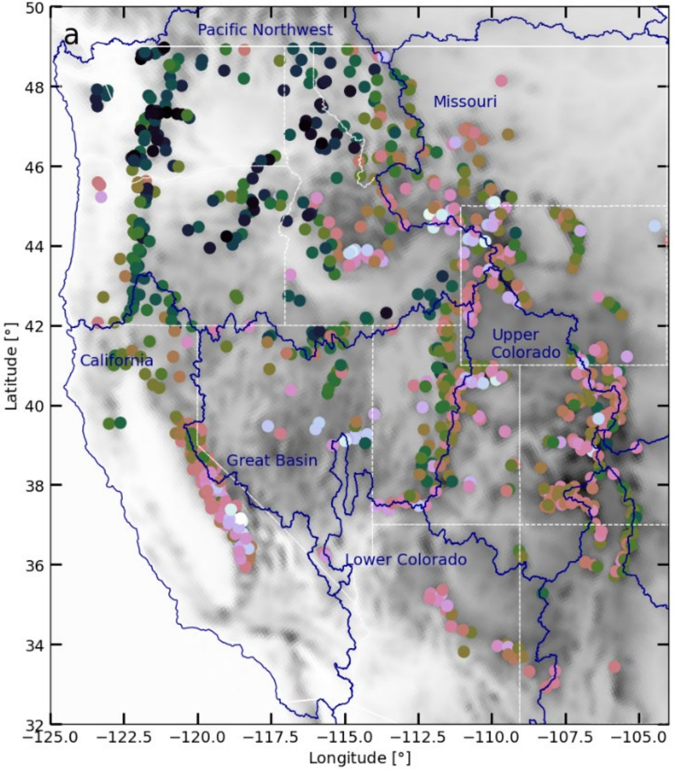

Snow pillow network in the western US (excluding Alaska)

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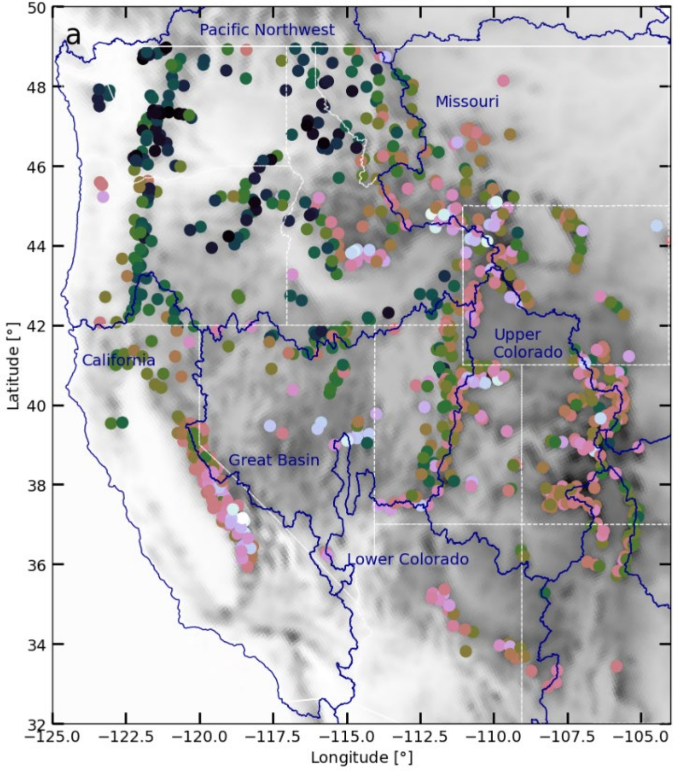
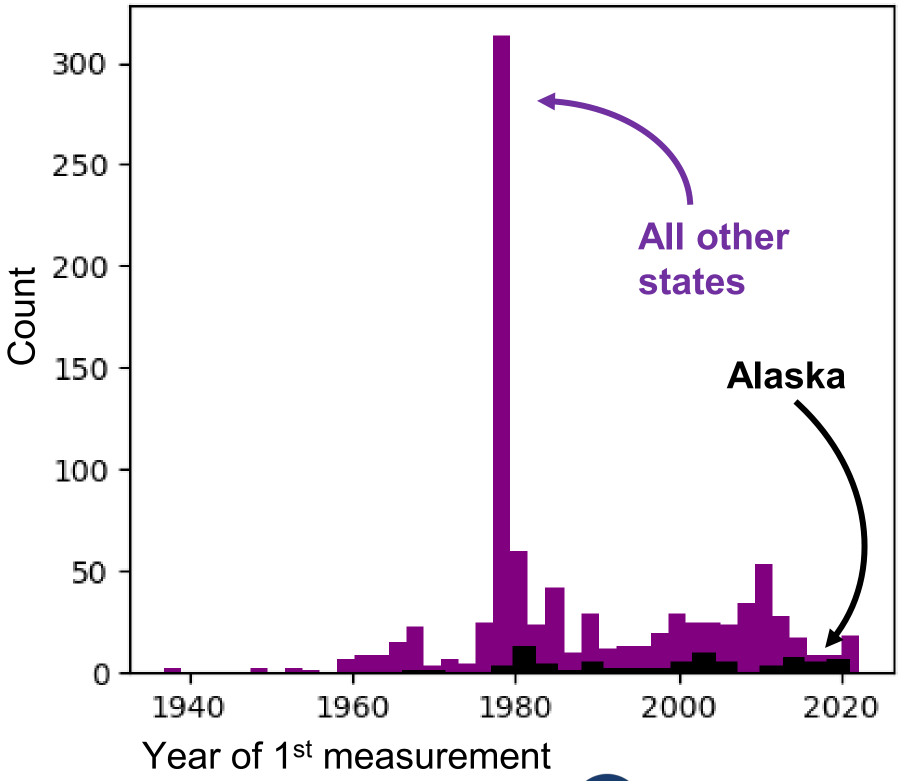
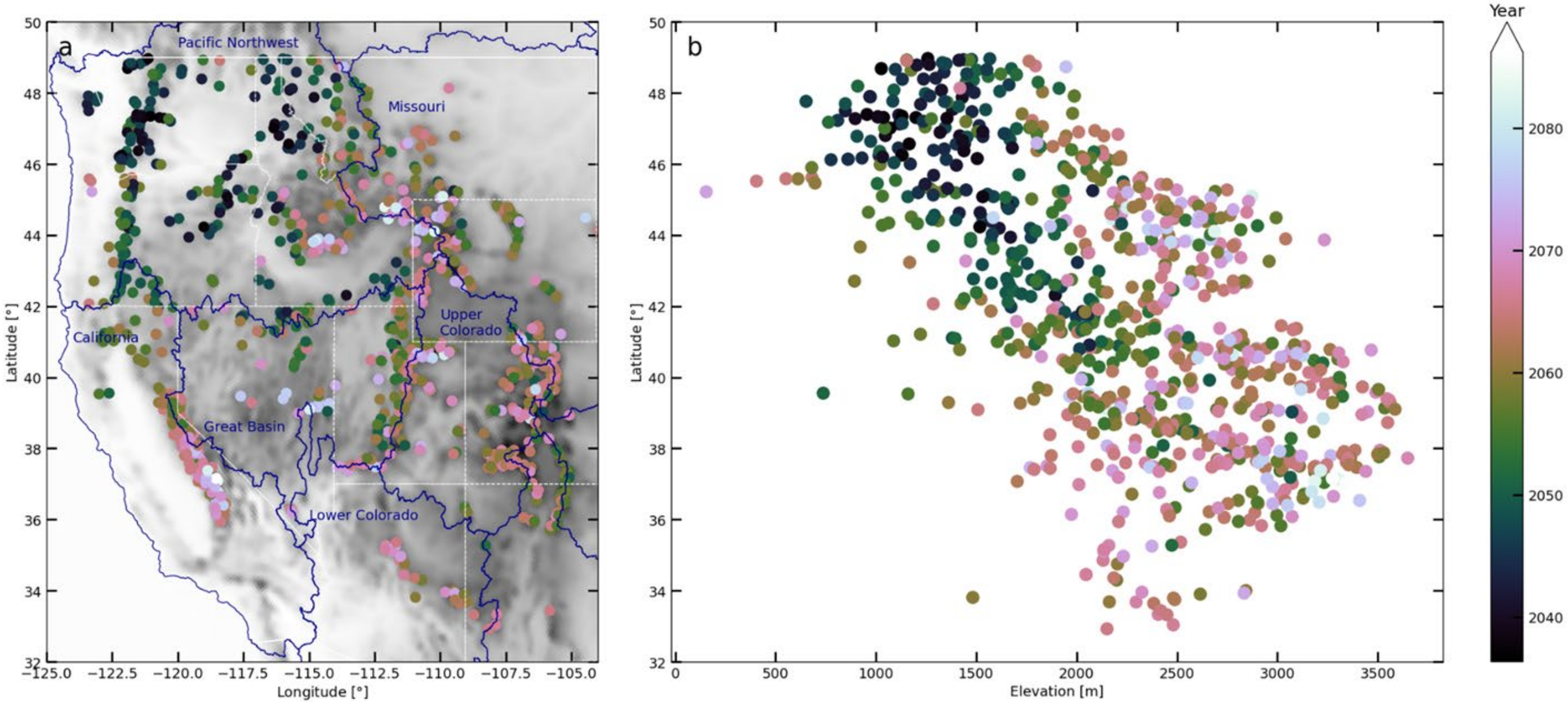


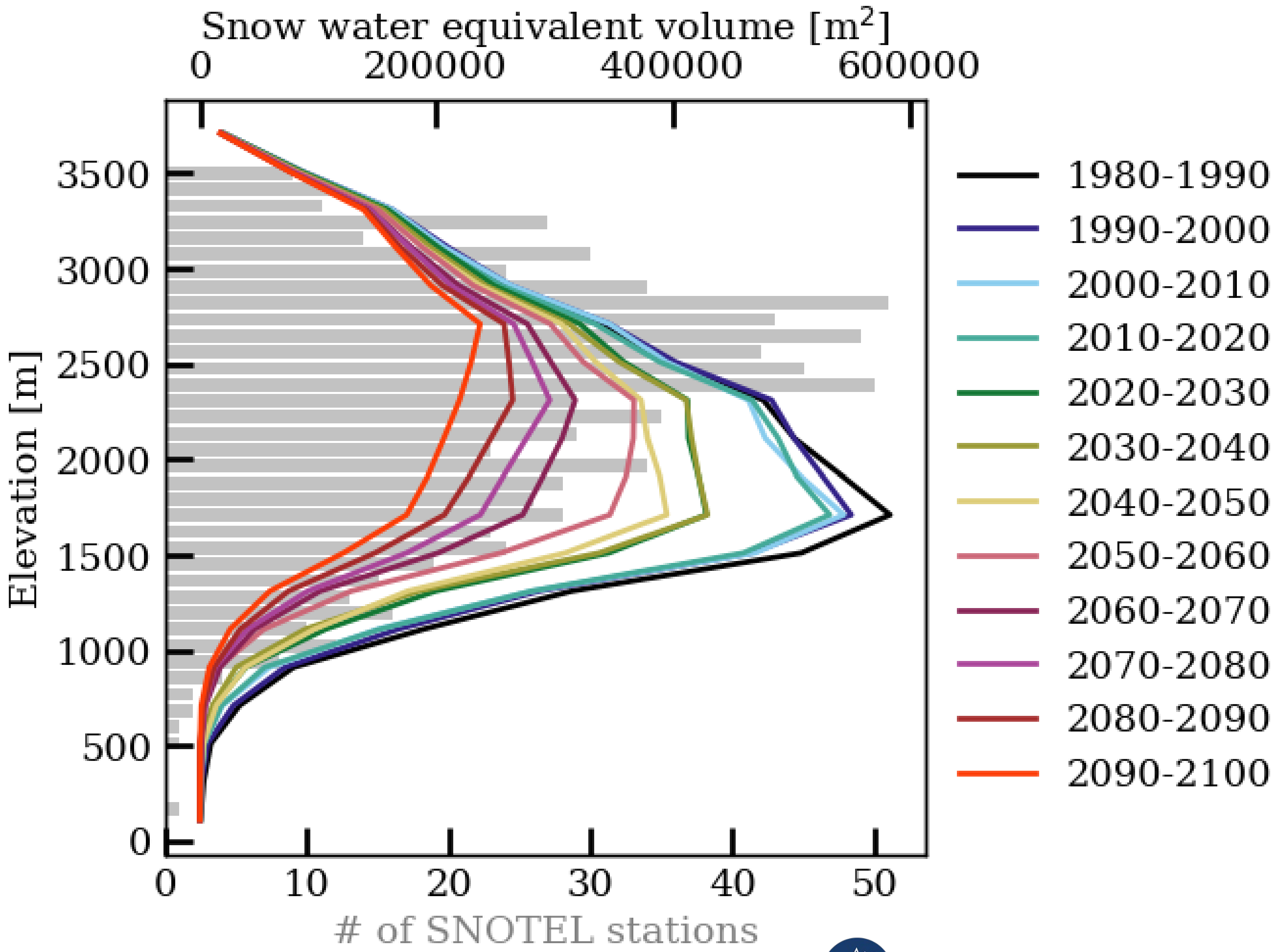




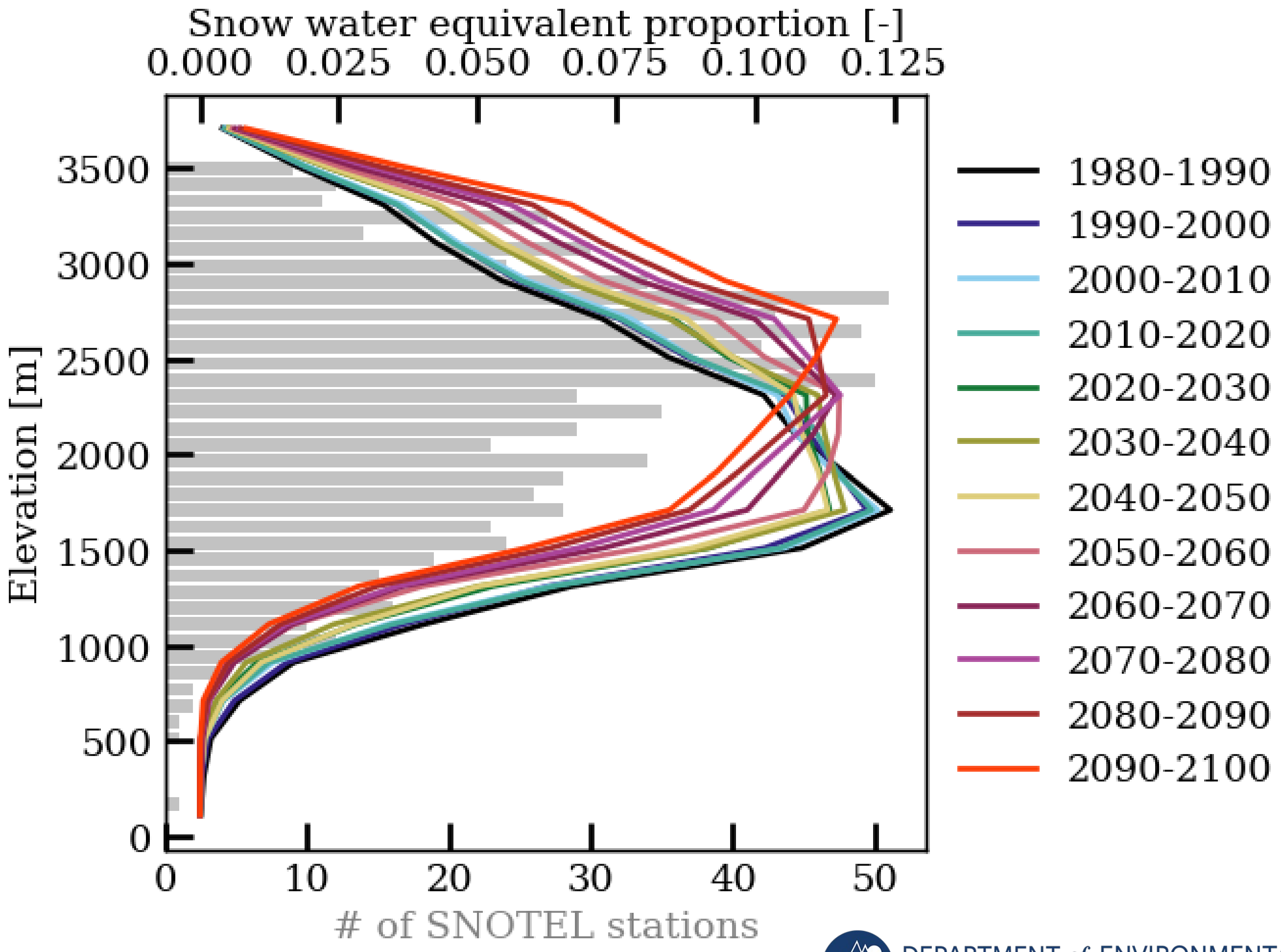
In what decade will half of measurements be below 10% of the historical mean peak snow water equivalent?

Cowherd et al. "Climate change-resilient snowpack estimation in the Western United States." *Communications Earth & Environment* 5.1 (2024): 337.

Snow distribution by decade from downscaled projections in **volume** units



Snow distribution by decade from downscaled projections by **proportion**



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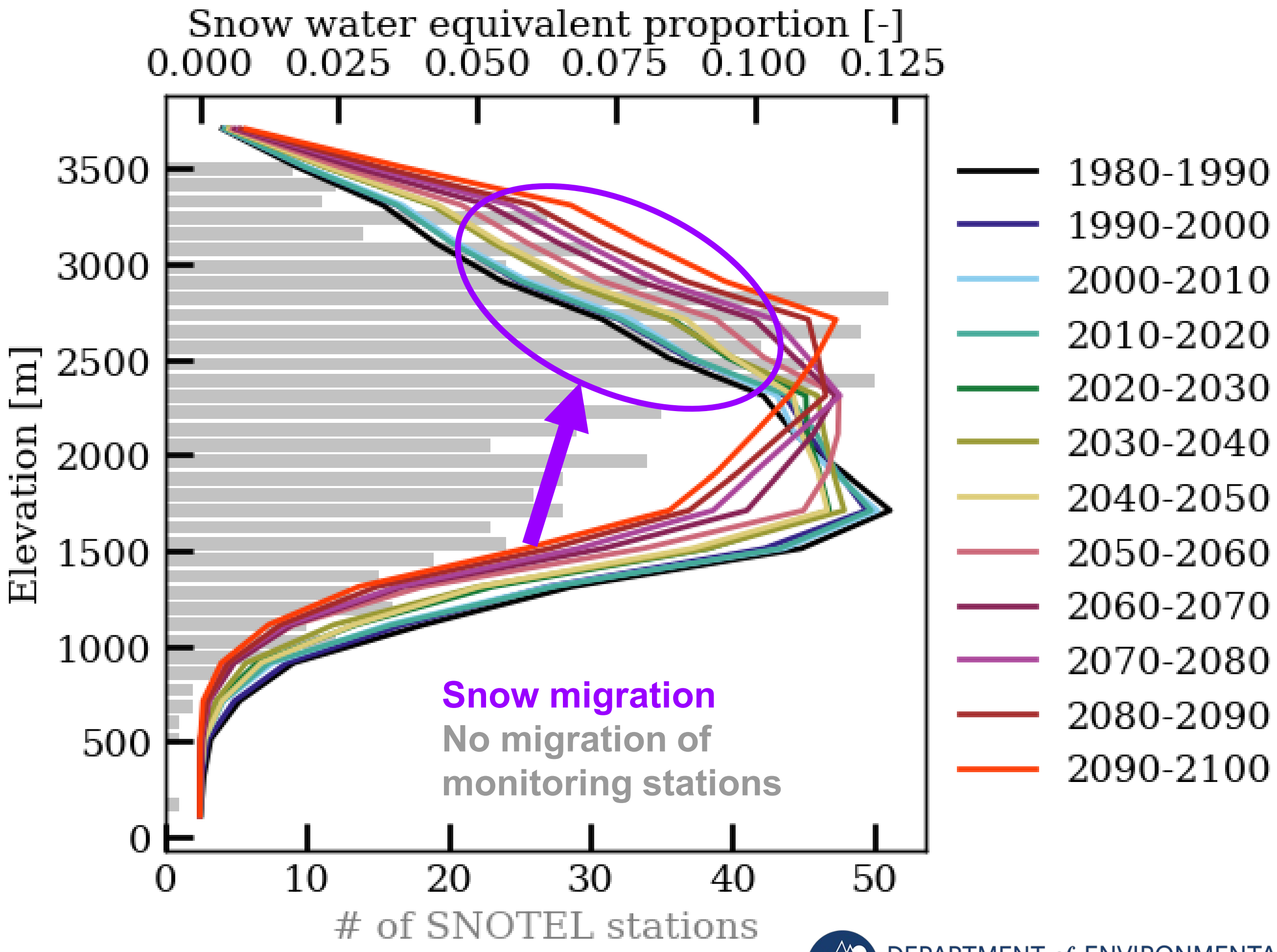

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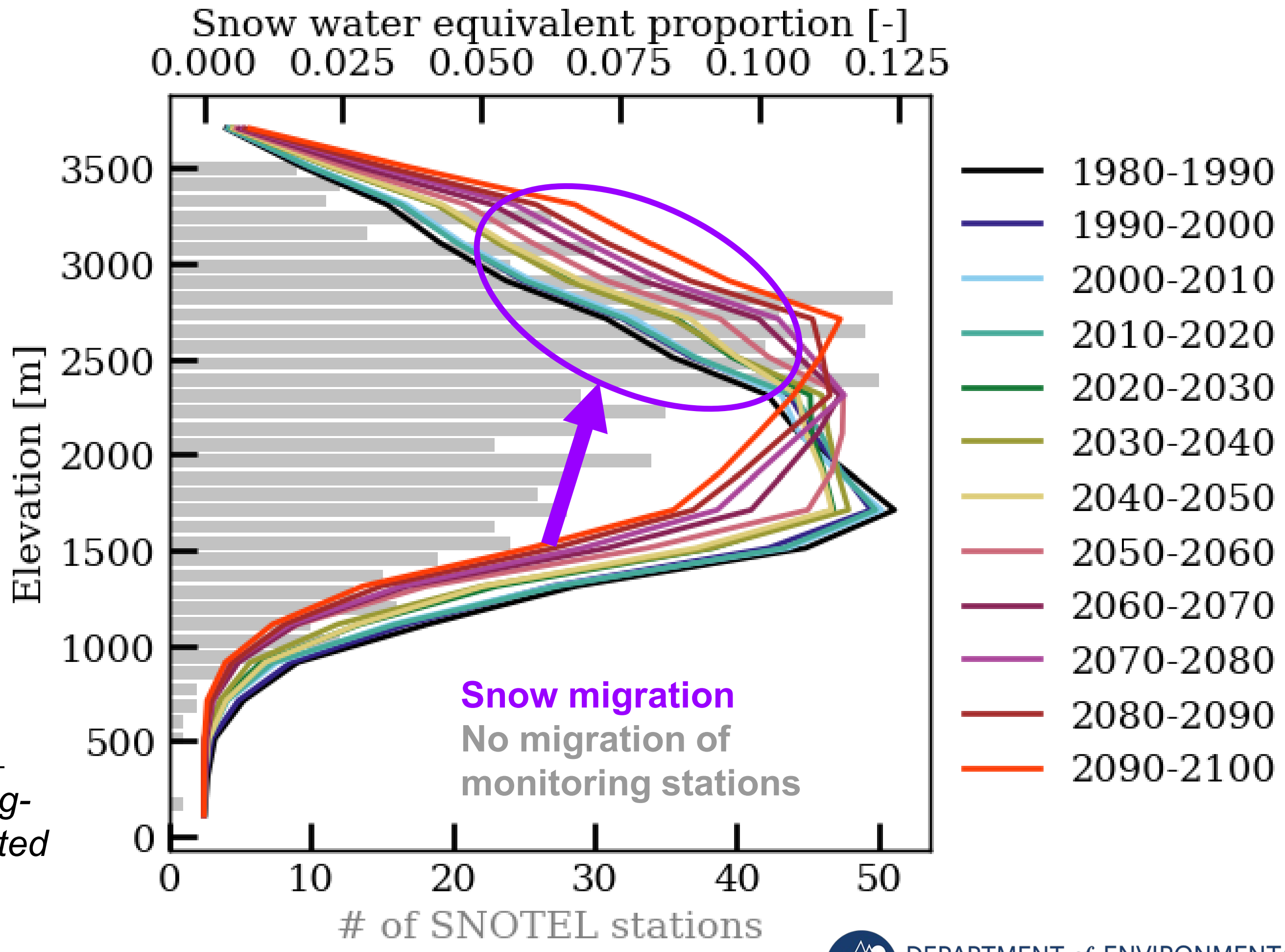
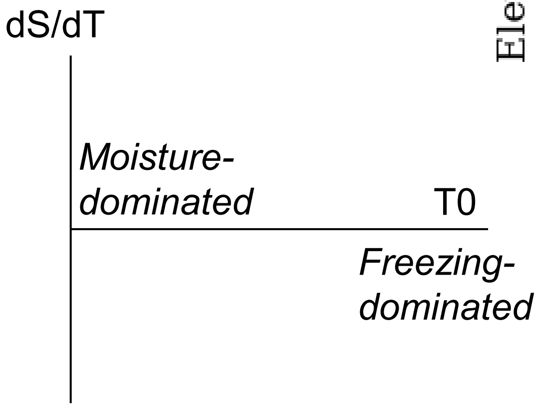
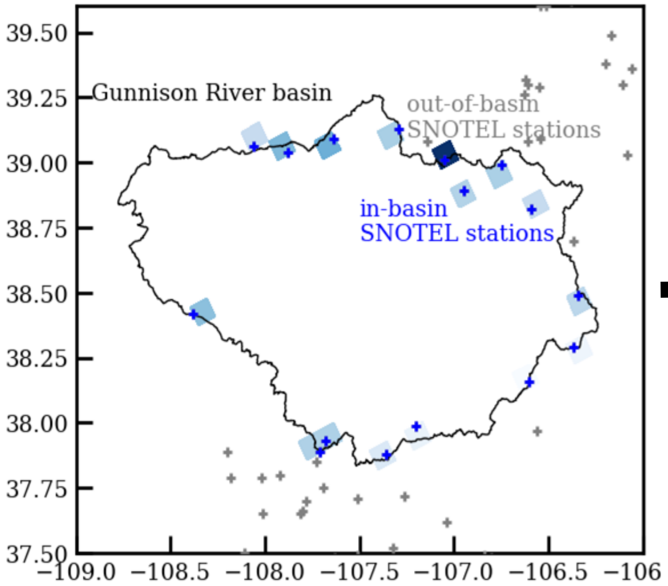


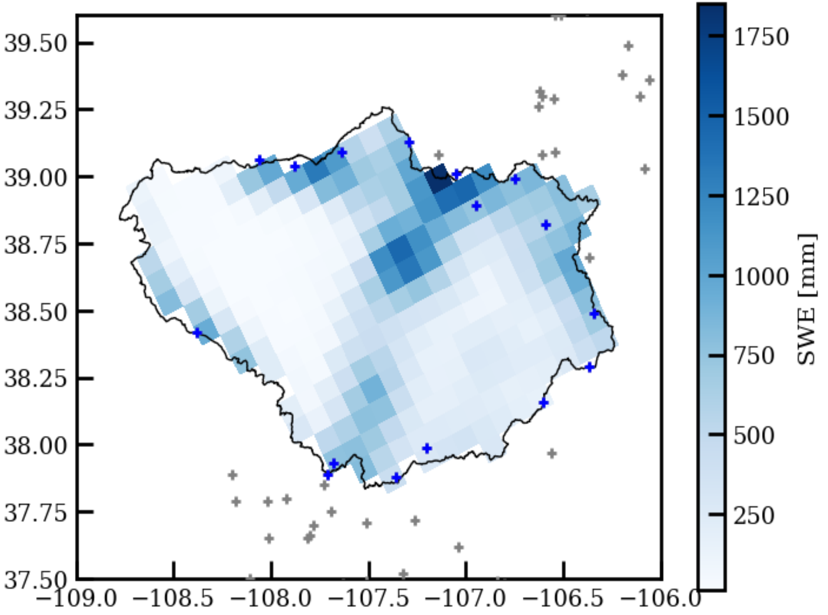


What we do in the catchments:



$$\Sigma a_j SWE_j + e = SWE_i$$

for j in-basin SNOTEL stations



$$Q = \sum_{i=1}^{n} a_i \mathrm{SWE}_i + e$$

Current management practices

"These predictions depend on the presence of **measurable snowpack**, as well as **a consistent relationship** between observed peak snow conditions and streamflow." -Livneh and Badger 2020

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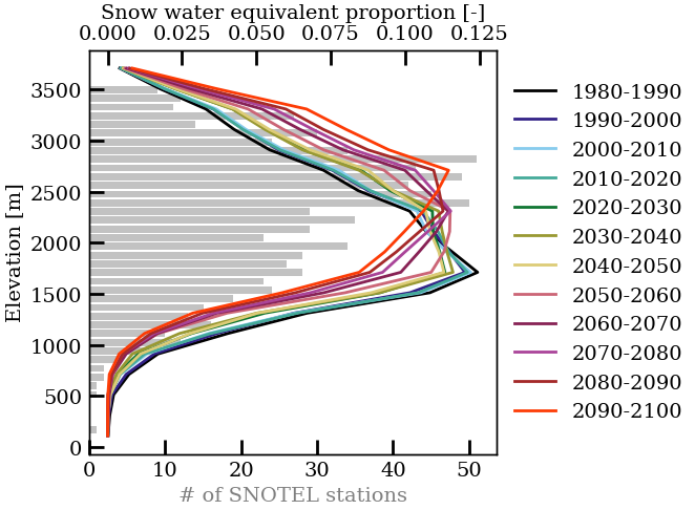

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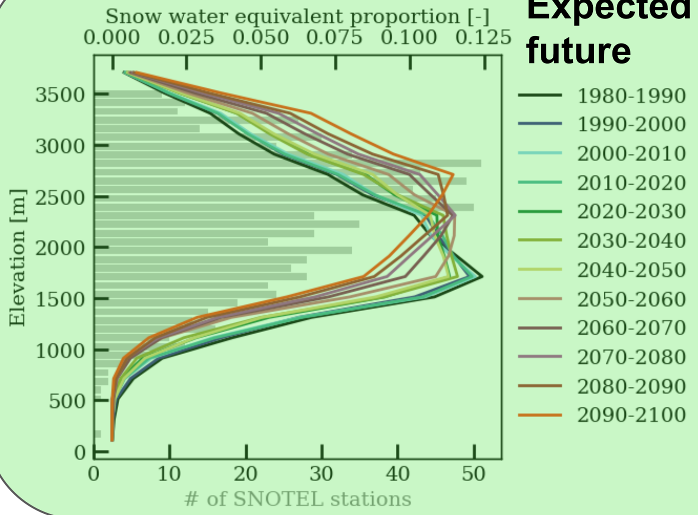
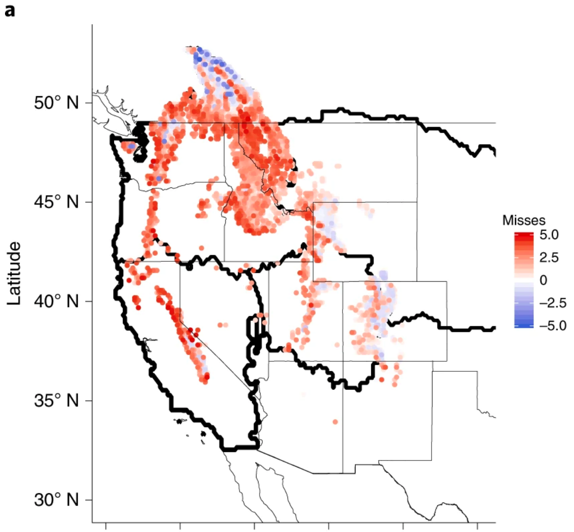
Expected future





Article | Published: 20 April 2020

Drought less predictable under declining future snowpack

Ben Livneh & Andrew M. Badger

Are snowpack patterns changing faster?

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POLICYFORUM

CLIMATE CHANGE

Stationarity Is Dead: Whither Water Management?

Climate change undermines a basic assumption that historically has facilitated management of water supplies, demands, and risks.

P. C. D. Milly,[1*] Julio Betancourt,[2] Malin Falkenmark,[3] Robert M. Hirsch,[4] Zbigniew W. Kundzewicz,[5] Dennis P. Lettenmaier,[6] Ronald J. Stouffer[7]

2008

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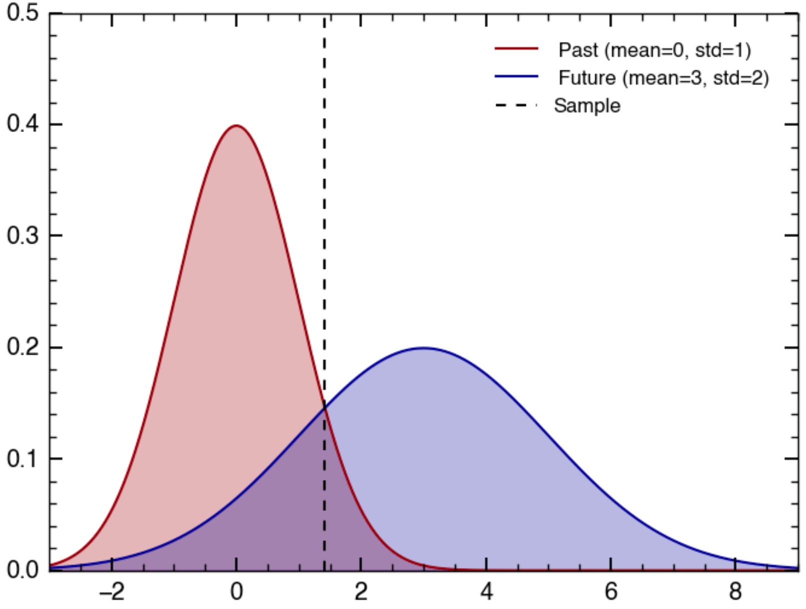

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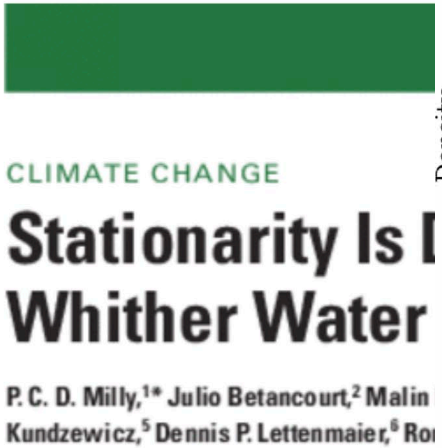

CLIMATE CHANGE

Stationarity Is I
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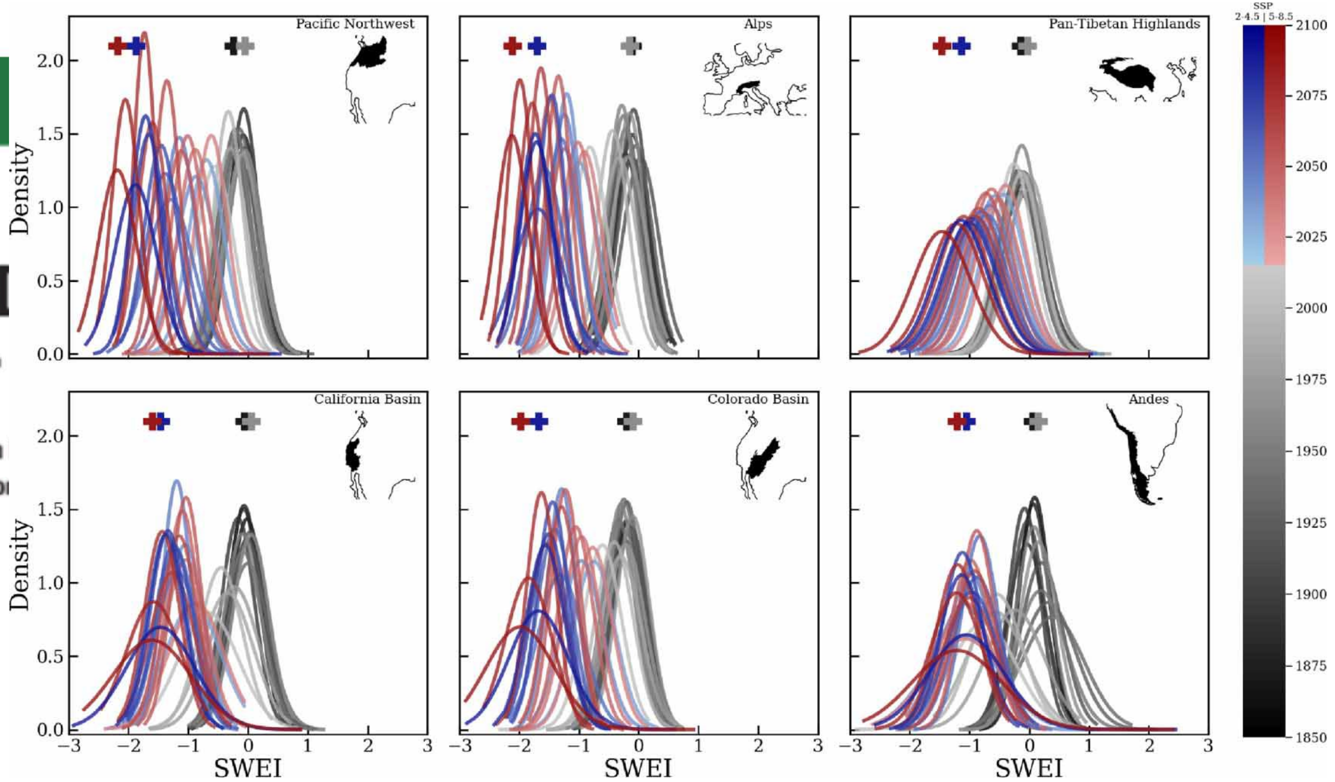
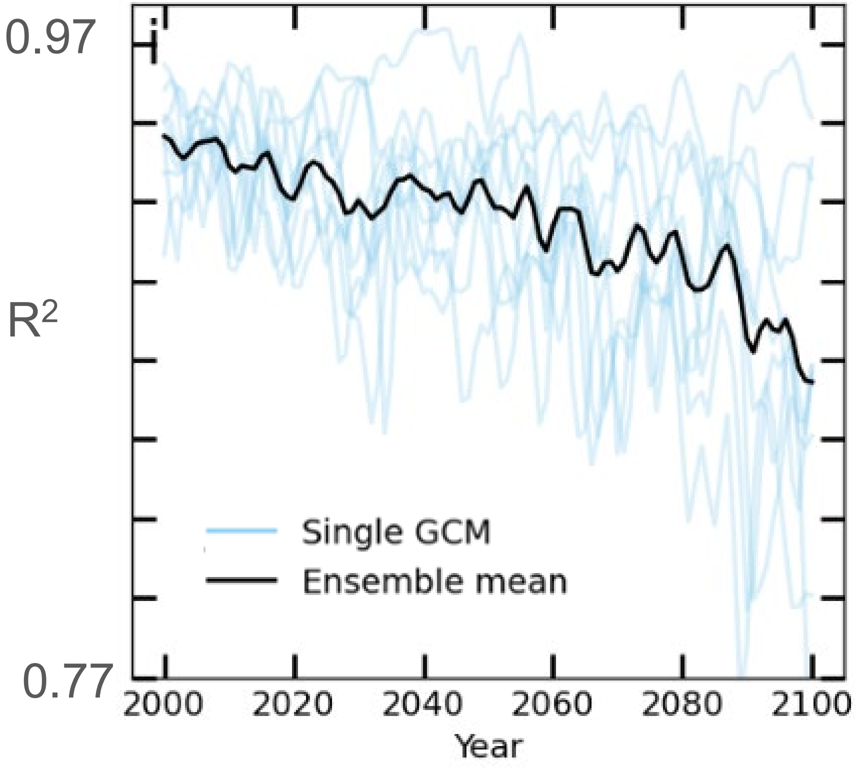


Cowherd et al., 2023 *ERL*

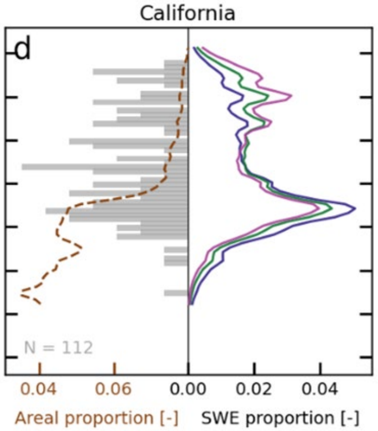
SWEI = Snow Water Equivalent Index
Anything below -0.8 is considered snow drought

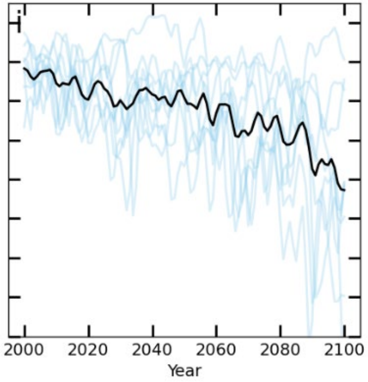
Are snowpack patterns changing faster?

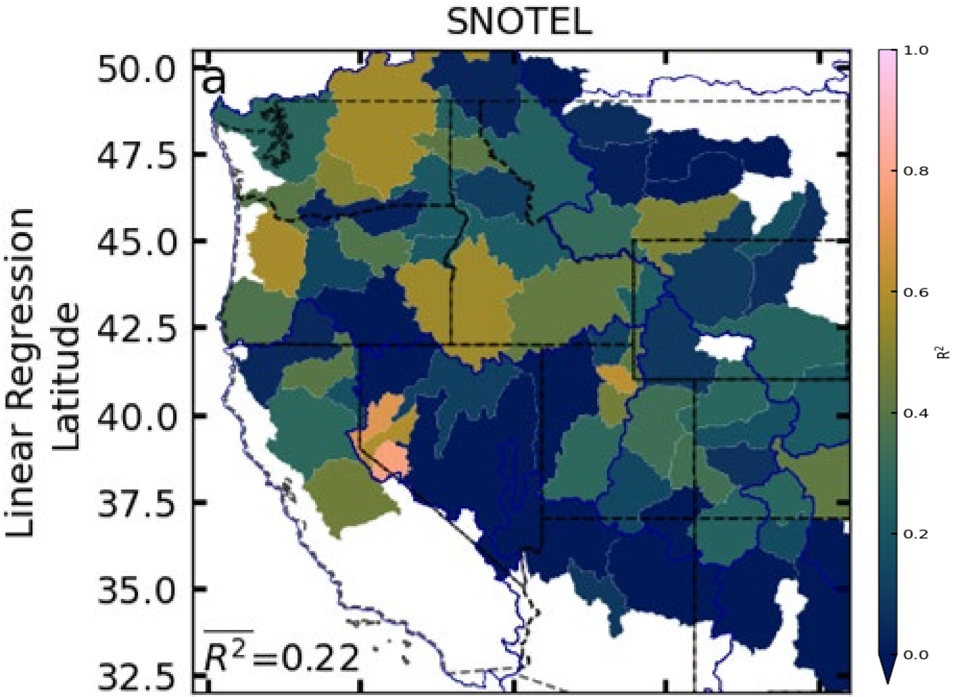
How similar are spatial patterns of snowpack to the previous 30 years?



When snowpack patterns change, can we use those measurements to make accurate predictions about the rest of the basin?







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How is snow measurement impacted by climate change?

A: Climate change makes it harder to use snow observations in traditional frameworks

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How is snow measurement impacted by climate change?

A: Climate change makes it harder to use snow observations in traditional frameworks

… because those frameworks do not reflect the underlying processes that control snow distribution

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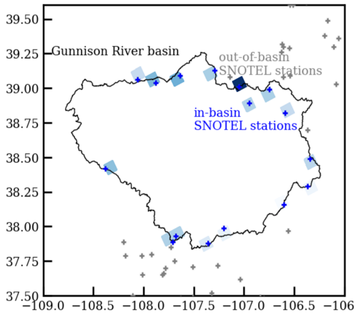
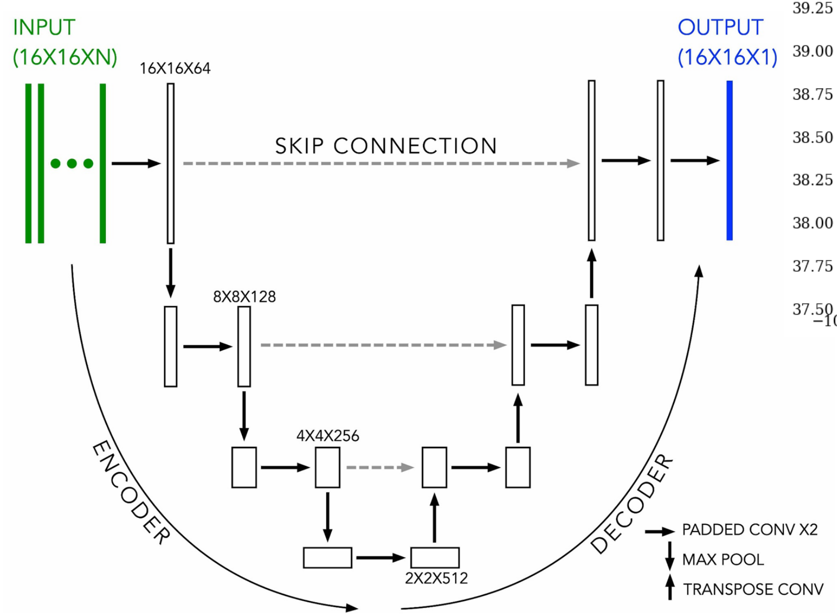
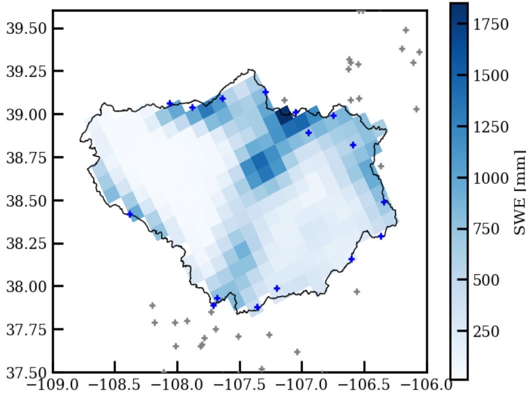
A U-Net can be a set of convolutions that represents why snow is distributed across a region

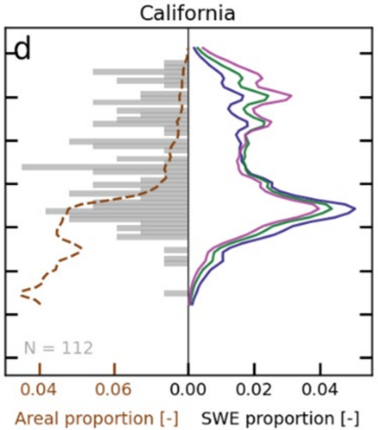


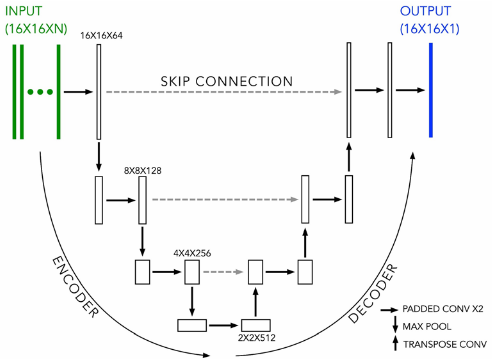


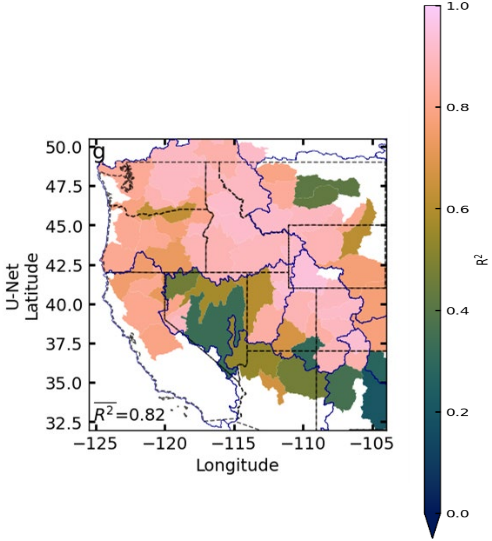


Cowherd et al., 2024

Try again, this time with the U-Net:







Cowherd et al., 2024

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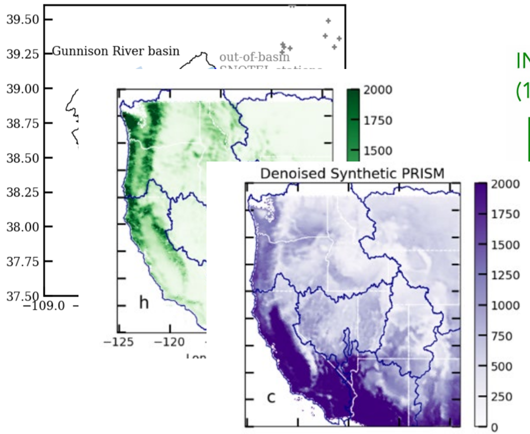

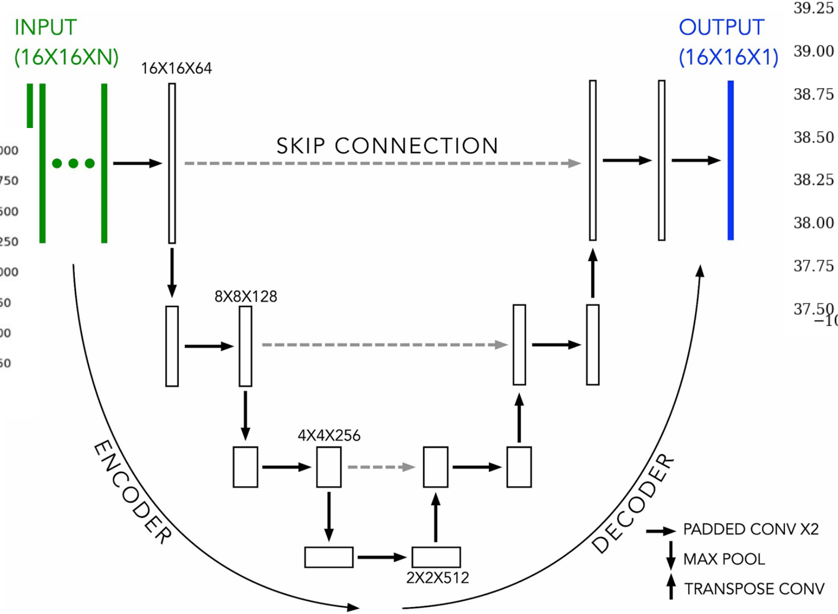

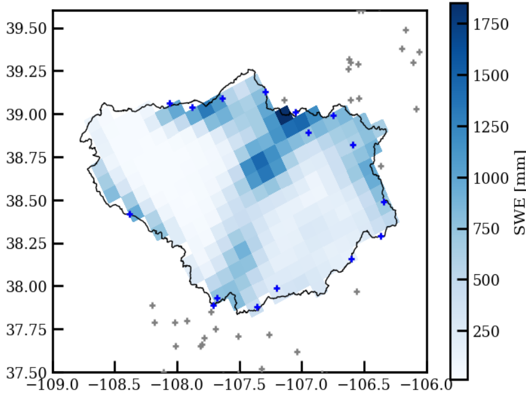

Cowherd et al., 2024

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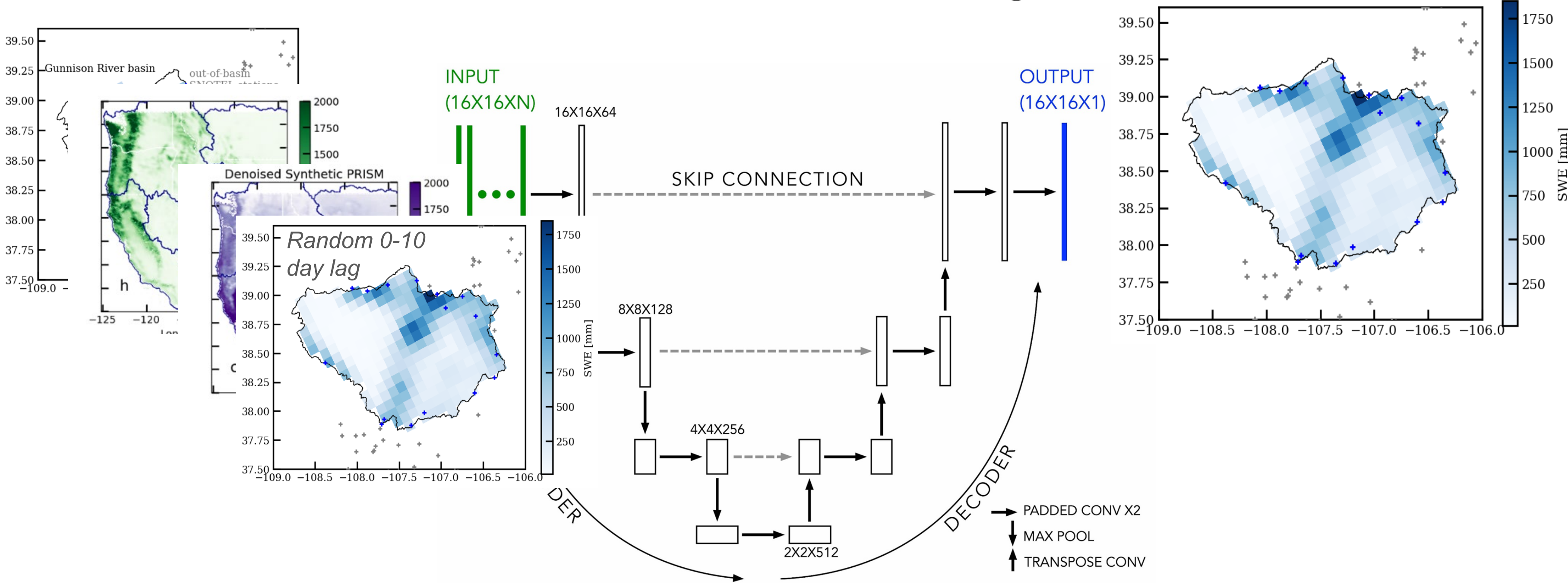
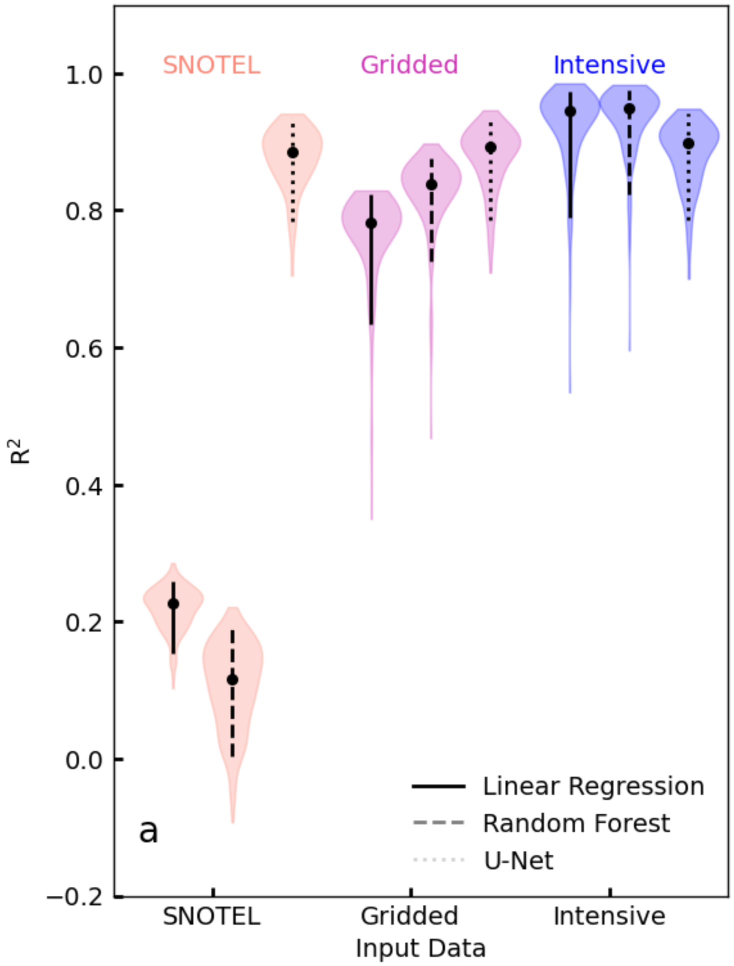
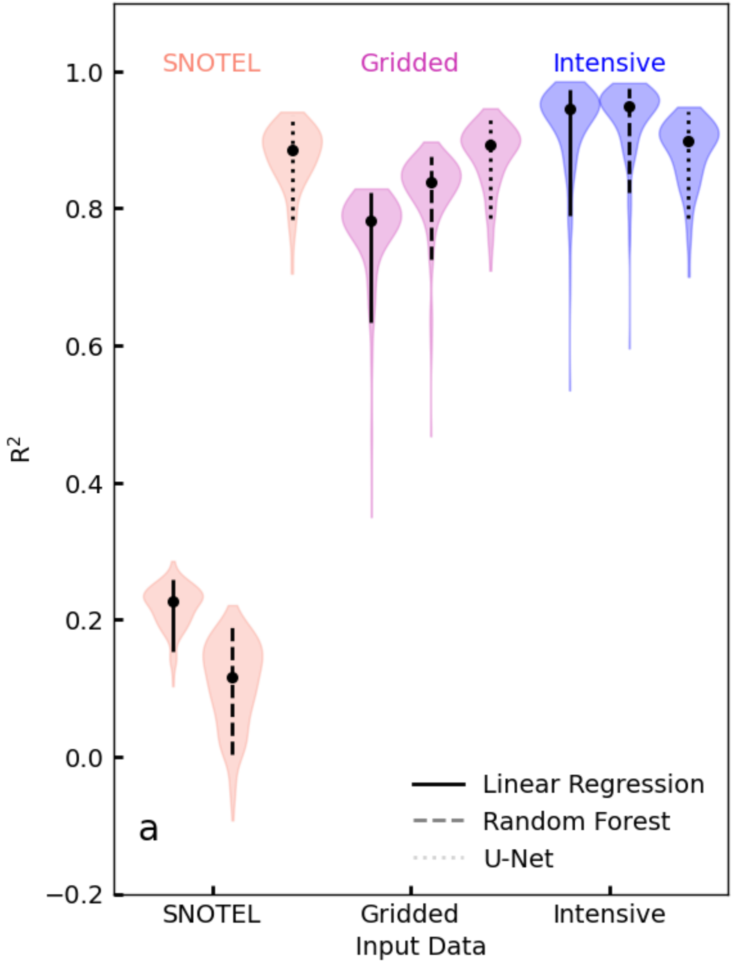


Cowherd et al., 2024



Cowherd et al., 2024



Cowherd et al., 2024

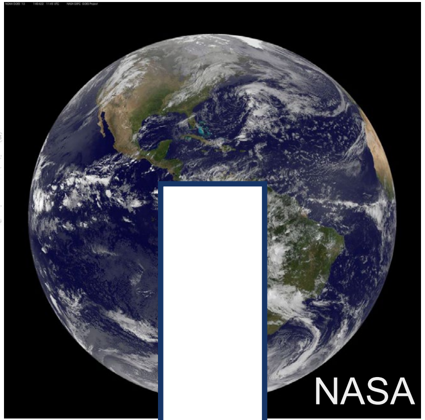
U-Net Pros:

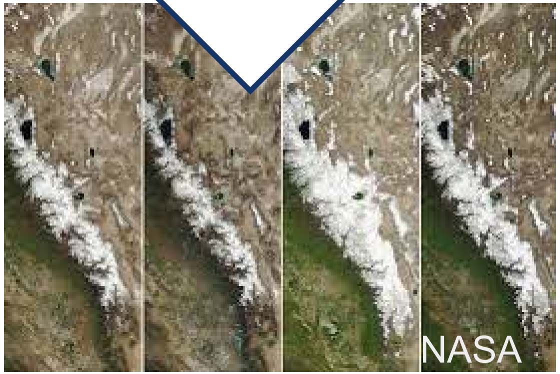
1. Works well with only snow pillow input
2. <u>Multi-scale model for a multi-scale process</u>
3. Robust to climate change
4. Robust to loss of observation
5. As high-resolution as your elevation map
6. Technically data-driven, theoretically physics-informed

U-Net Cons:

1. Computationally expensive*
2. Extra work to make it explainable
3. Not inherently physical

Interpreting models: Connecting regional processes to local observations

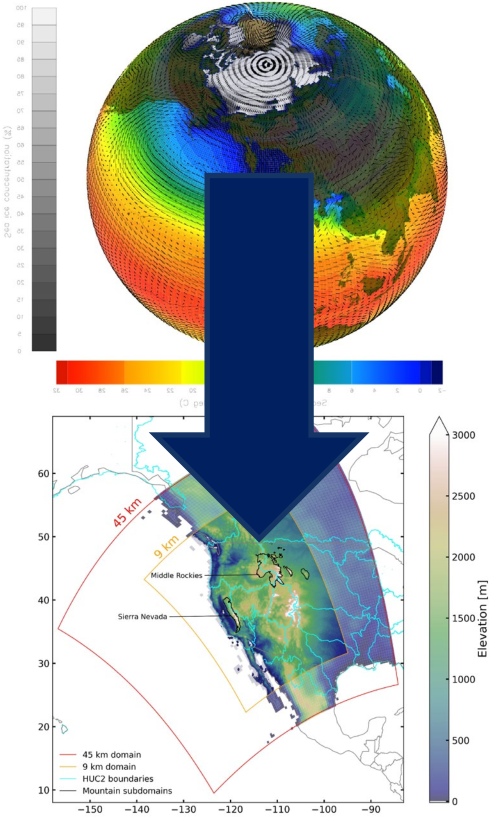




In real life:

Regional snow amounts are distributed locally by elevation, latitude, topographic position, vegetation, albedo variations, local clouds, subsequent rain, etc.

Interpreting models: Connecting regional processes to local observations



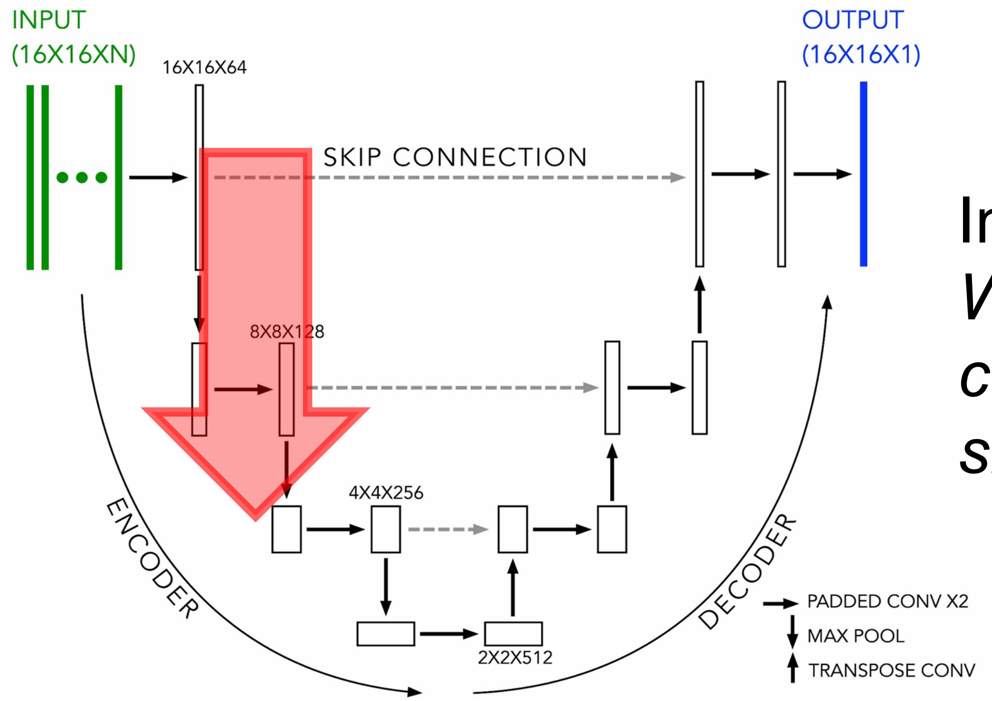
In the training data:

Numerically connecting 1-degree scale atmospheric states to sub-10-km-scale snowpack.

- *Some direct representation of processes*
- *Some parameterization*
- *Some missing*

Cowherd et al., 2024

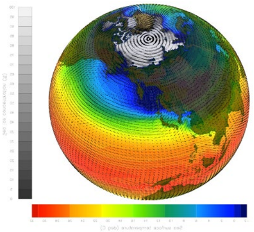
Interpreting models: Connecting regional processes to local observations



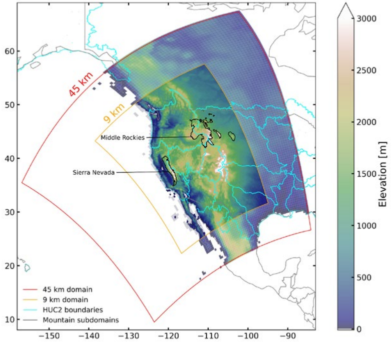
In the neural network:
We try to learn a set of convolutions that represent snow processes.

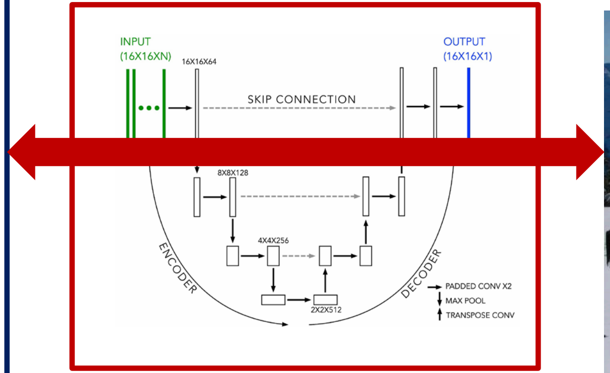
Cowherd et al., 2024

Machine learning for climate-**resilient*** measurement interpretation



How will the climate change?





What are we measuring that reflects this change?

Rahimi, Stefan, et al. "An overview of the western United States dynamically downscaled dataset (WUS-D3)." *Geoscientific Model Development* 17.6 (2024): 2265-2286.

Summary

Climate change-driven nonstationarity introduces unique challenges in interpreting measurements, especially for management

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Snowpack is a sentinel for climate-hydrology feedbacks

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Machine learning techniques – when appropriately matched to the environmental system – can make measurements *more* useful. Sometimes it is <u>mandatory</u>.

Summary

Climate change-driven nonstationarity introduces unique challenges in interpreting measurements, especially for management

Snowpack is a sentinel for climate-hydrology feedbacks

Machine learning techniques – when appropriately matched to the environmental system – can make measurements *more* useful. Sometimes it is mandatory.

Machine learning is a useful tool for bridging observations and simulations

Contact: cowherd@berkeley.edu

Thank you!

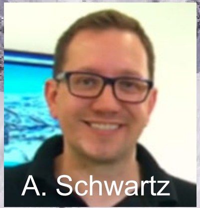

Photo: Jeremy Snyder/LBL EESA