Remote Sensing and Modeling of Snowpack Dynamics During the Record 2026 Snow Drought

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Photo: Jim Steenburgh

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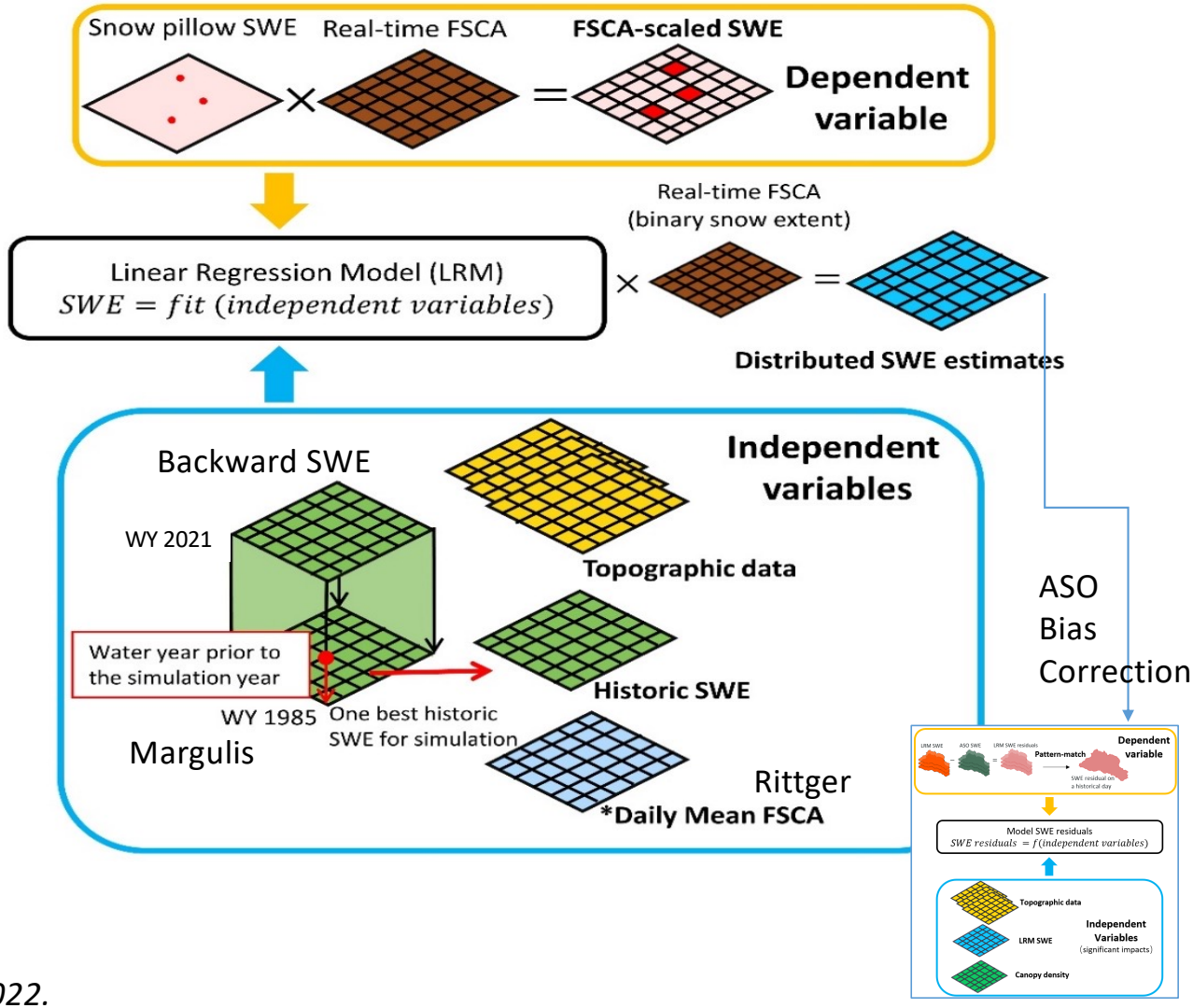
Objectives

- Objective 1: How much water was stored in the mountain snowpack during the 2026 snow drought?

- Objective 2: How can new snow observing technologies improve water management during snow drought?

SWE Fusion

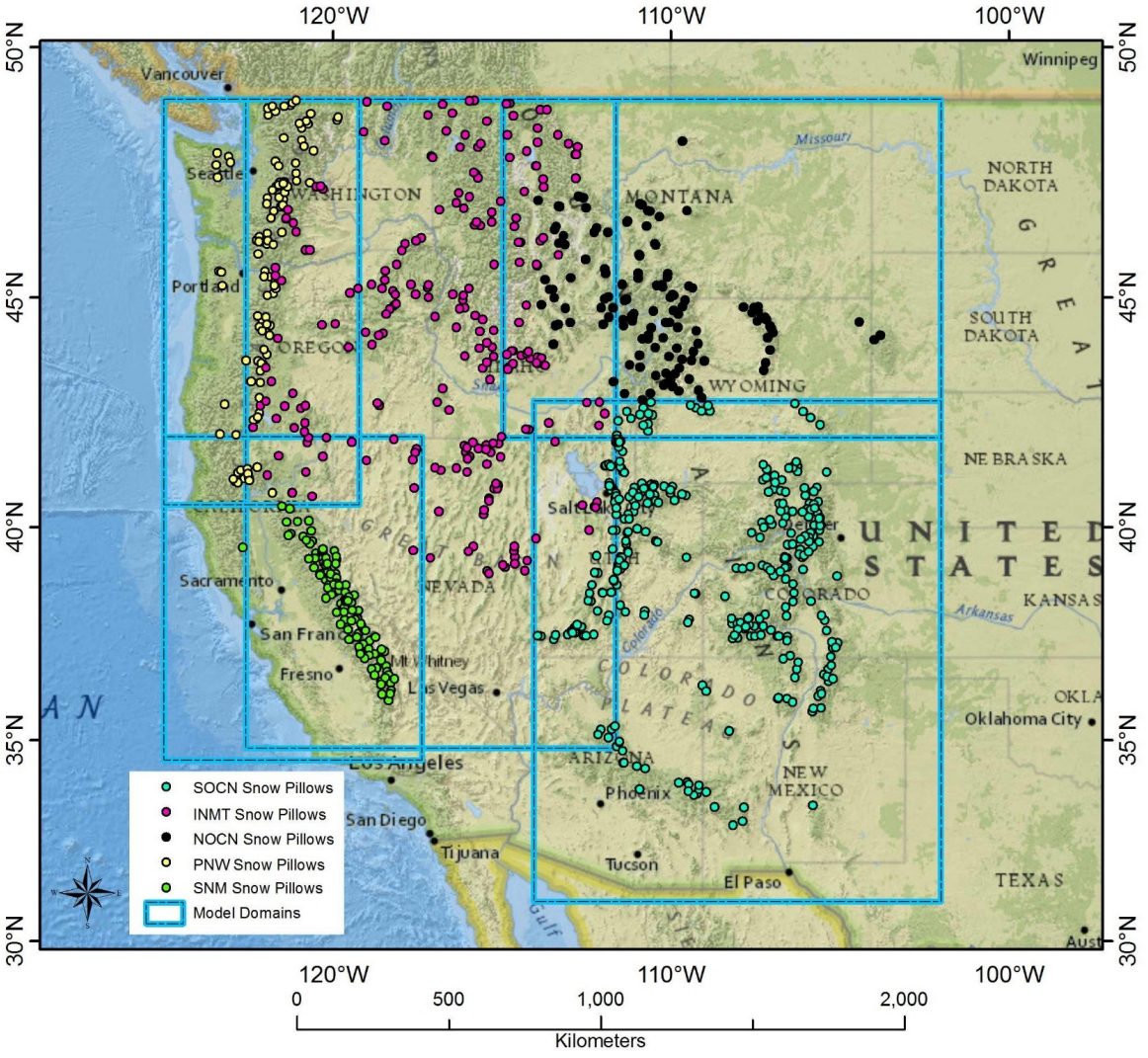
- Generalized Linear Regression Model (LRM).
- Dependent variable = ground-based SWE.
- Independent variables include satellite-based SWE reanalysis and FSCA
- Independent variables also include terrain-based metrics.



Yang et al., Advances in Water Resources, 2022.

SWE-Fusion
West-wide SWE

- 5 distinct regions will be analyzed independently.
- Clustering based on Snow senso analysis in Trujillo & Molotch, 2014 – WRR.
- Real-time SWE data generated Feb – May 2025 and 2026; forthcoming through 2029.

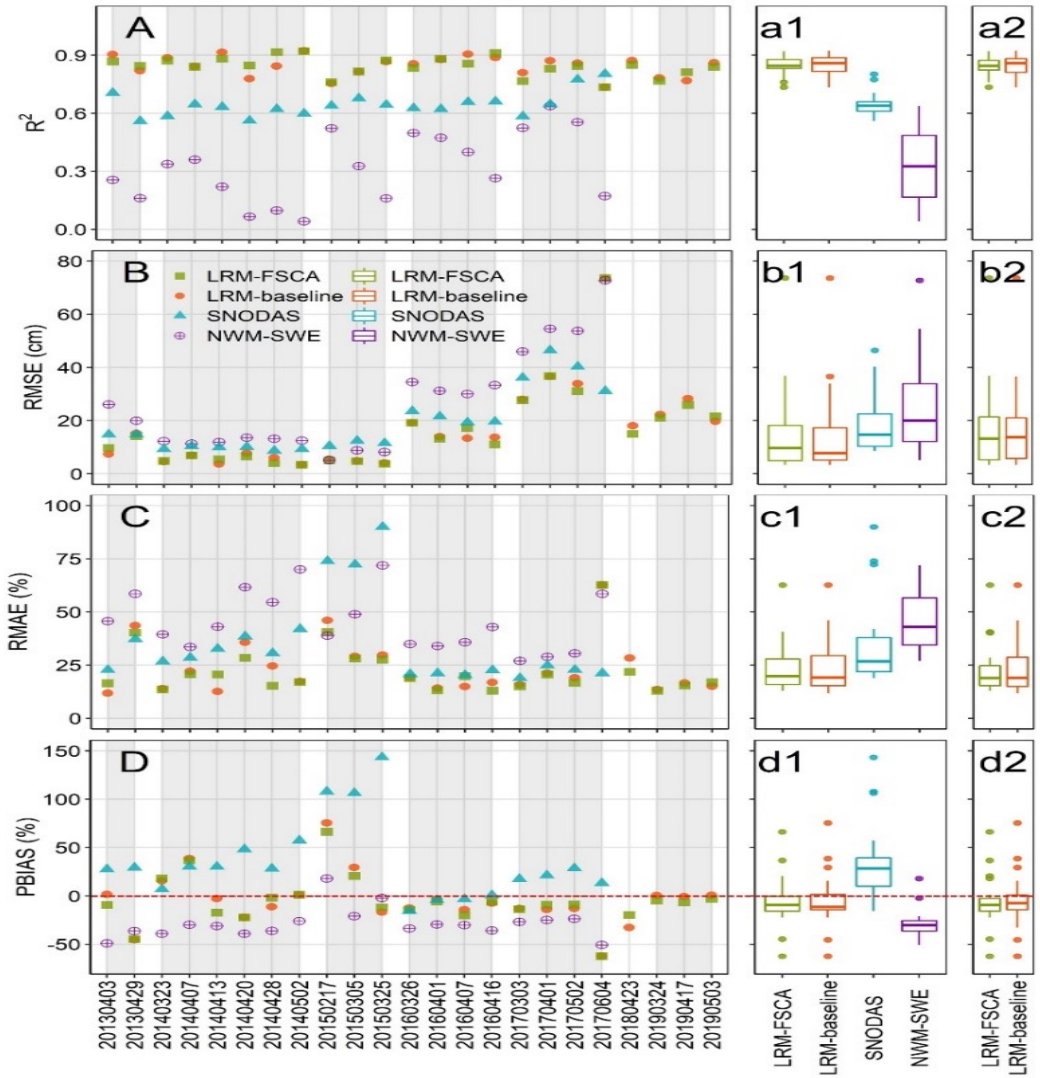


— BUREAU OF —
RECLAMATION

SWE-Fusion Accuracy

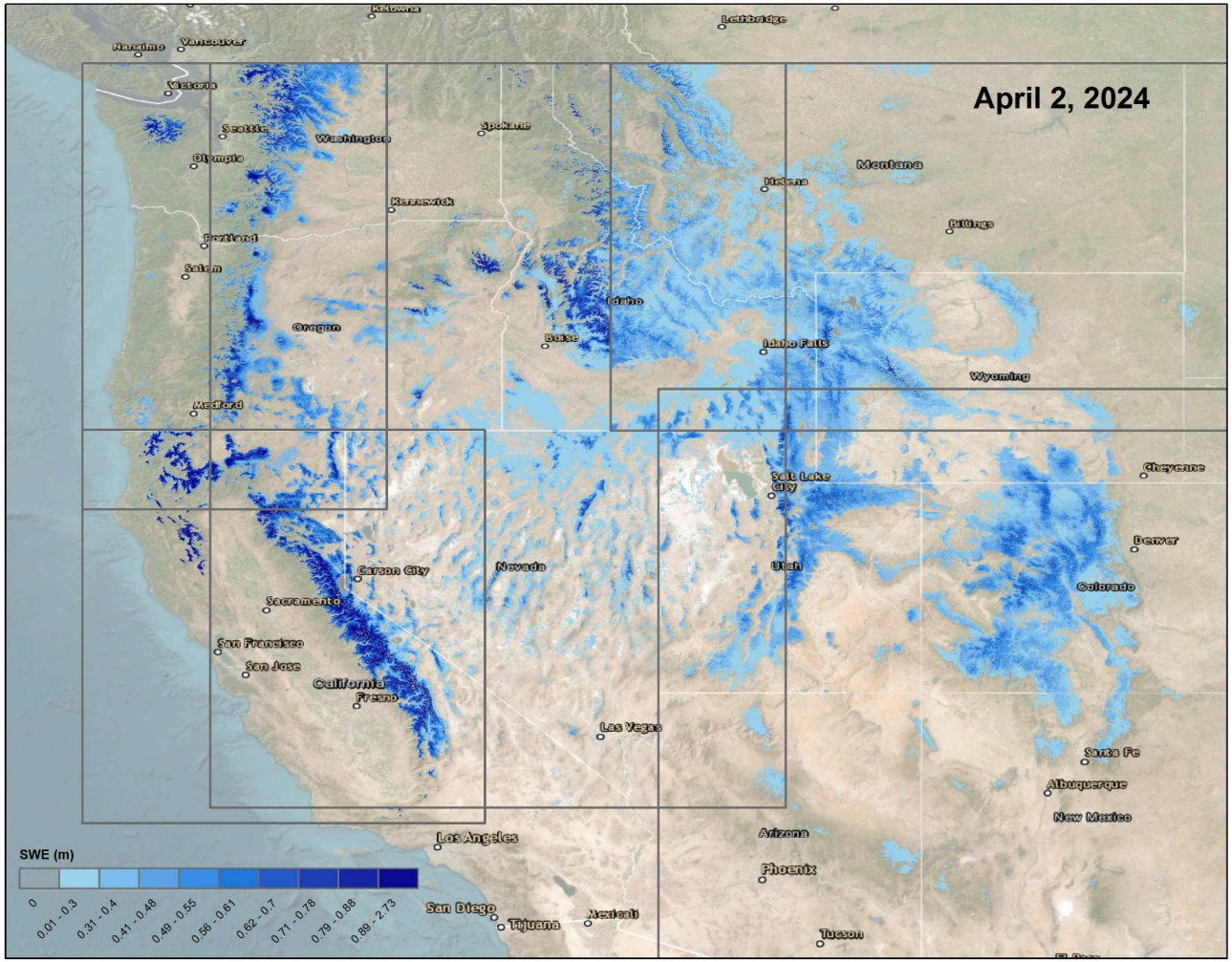
- SWE Fusion consistently exhibits:
  - Higher correlation with ASO SWE estimates when compared with US NWS SWE products.
  - Lower RMSE and lower relative mean absolute error.
  - Lower percent bias.

Yang et al., Advances in Water Resources, 2022



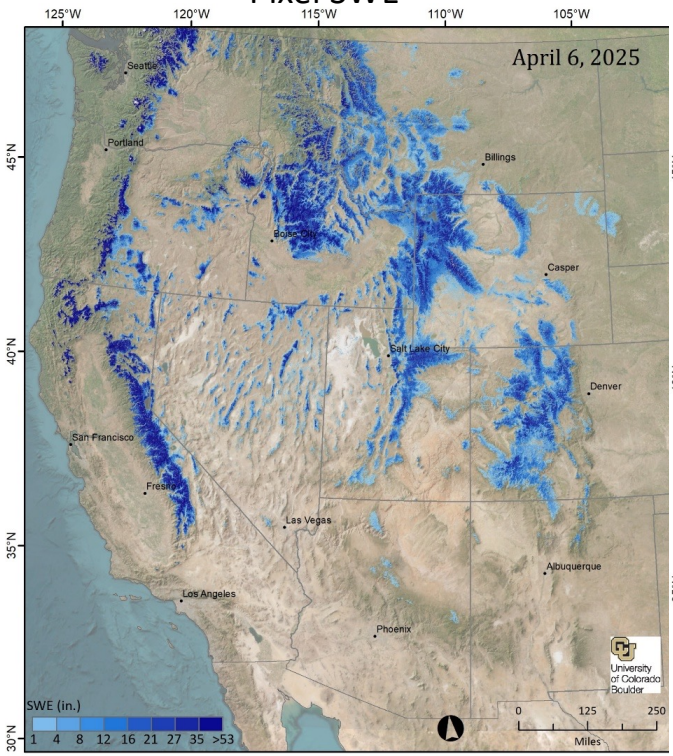
West-wide SWE April 2, 2024

- SWE depth and volume is reported for HUC8 basins & elevation bands.
- Gridded Geotiffs available for distribution.
- Summary reports prepared in co-production with water managers.

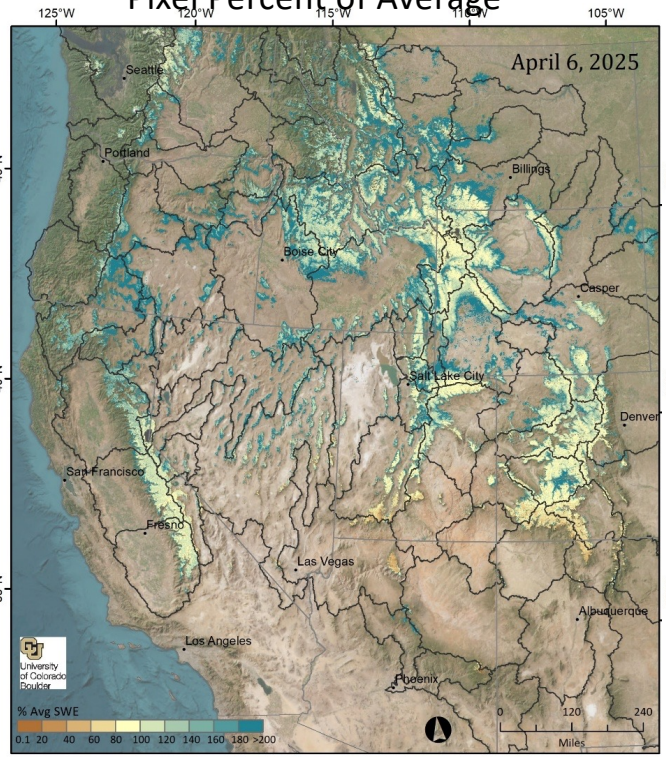


SWE-Fusion, Western US April 6, 2025

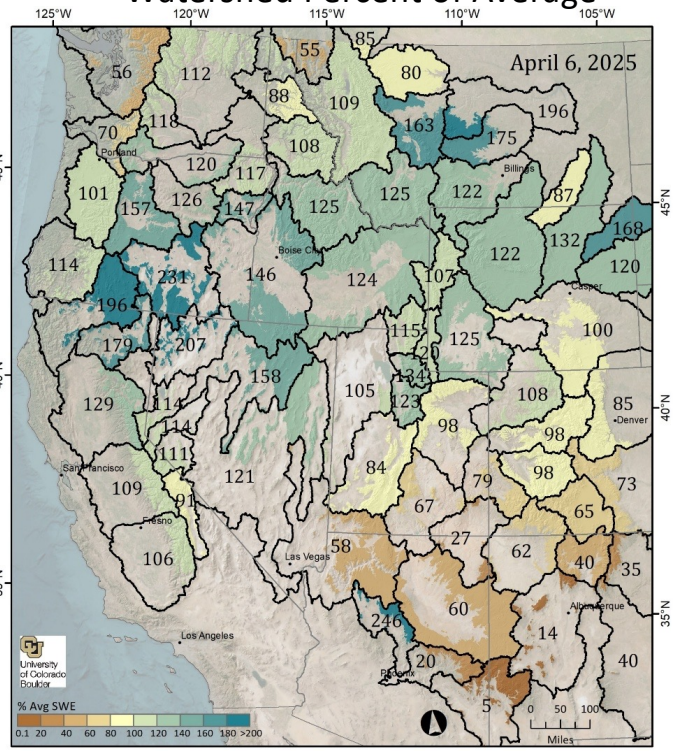
Pixel SWE



Pixel Percent of Average

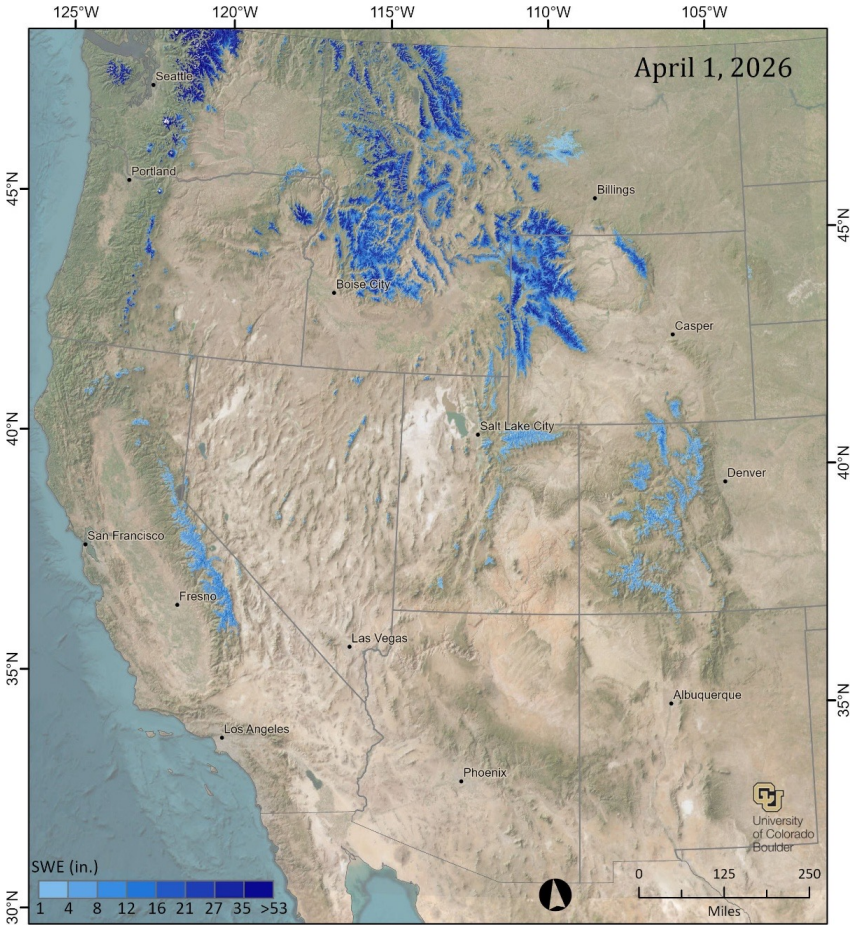


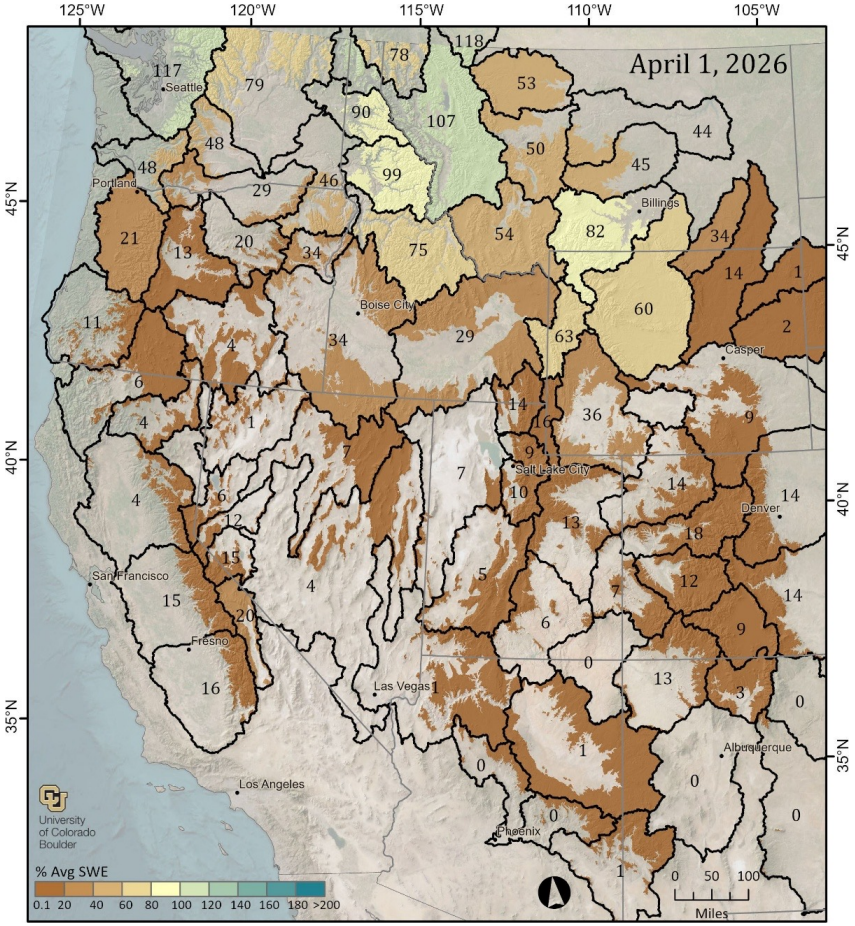
Watershed Percent of Average



Now available in real-time via USBR (and retrospectively back to 2001)

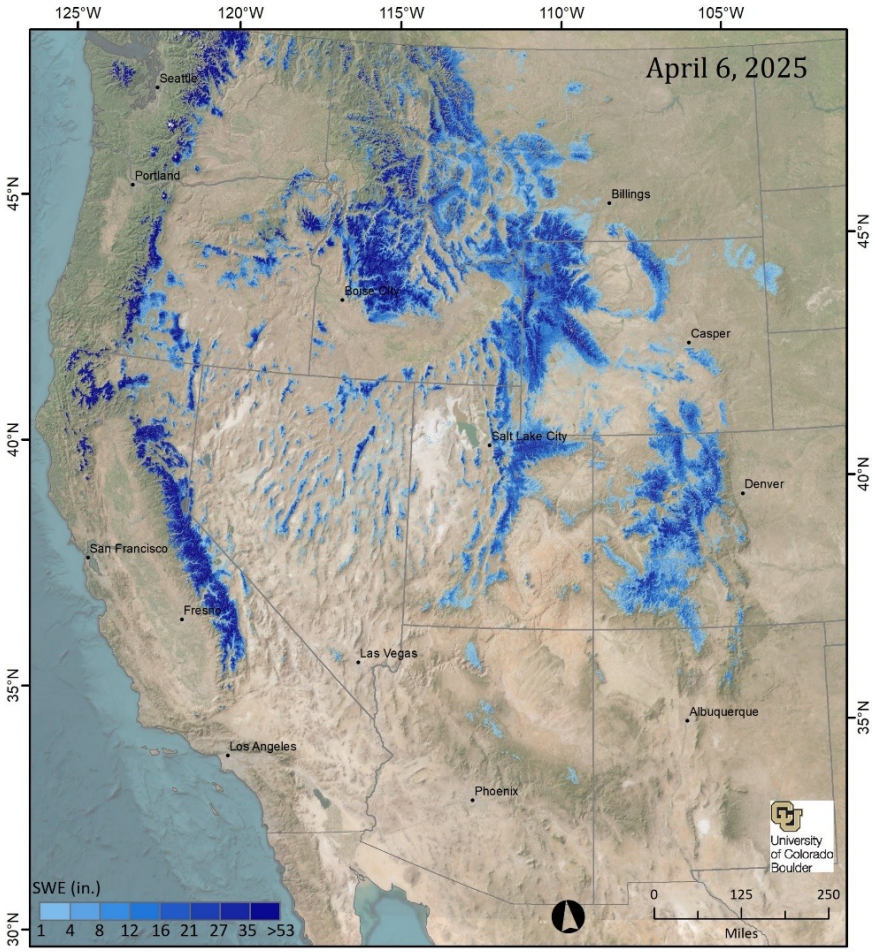
SWE-Fusion: Western US April 1, 2026



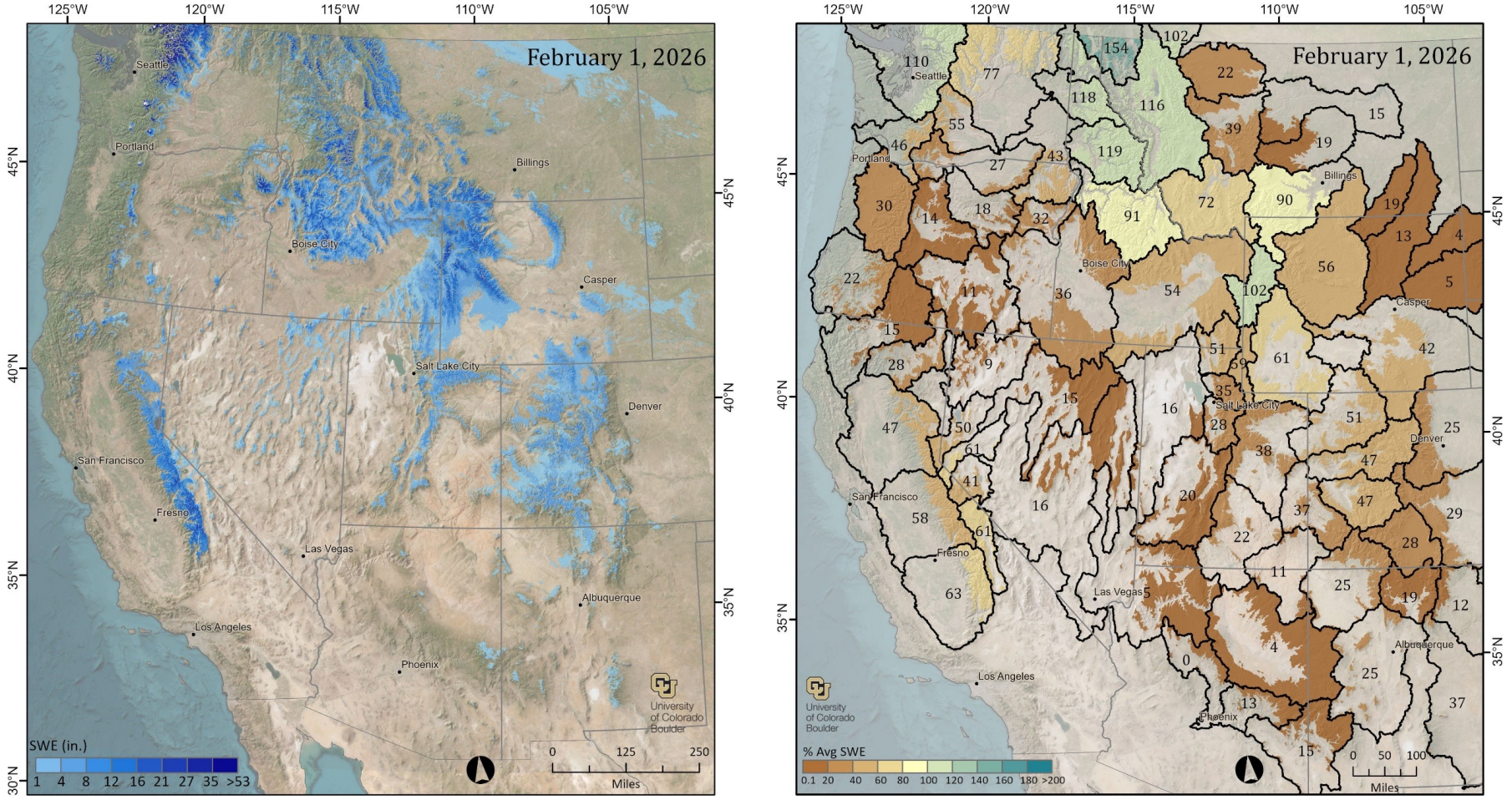


Source: INSTAAR Mountain Hydrology: Noah Molotch

SWE-Fusion, Western US April 2025 vs April 2026

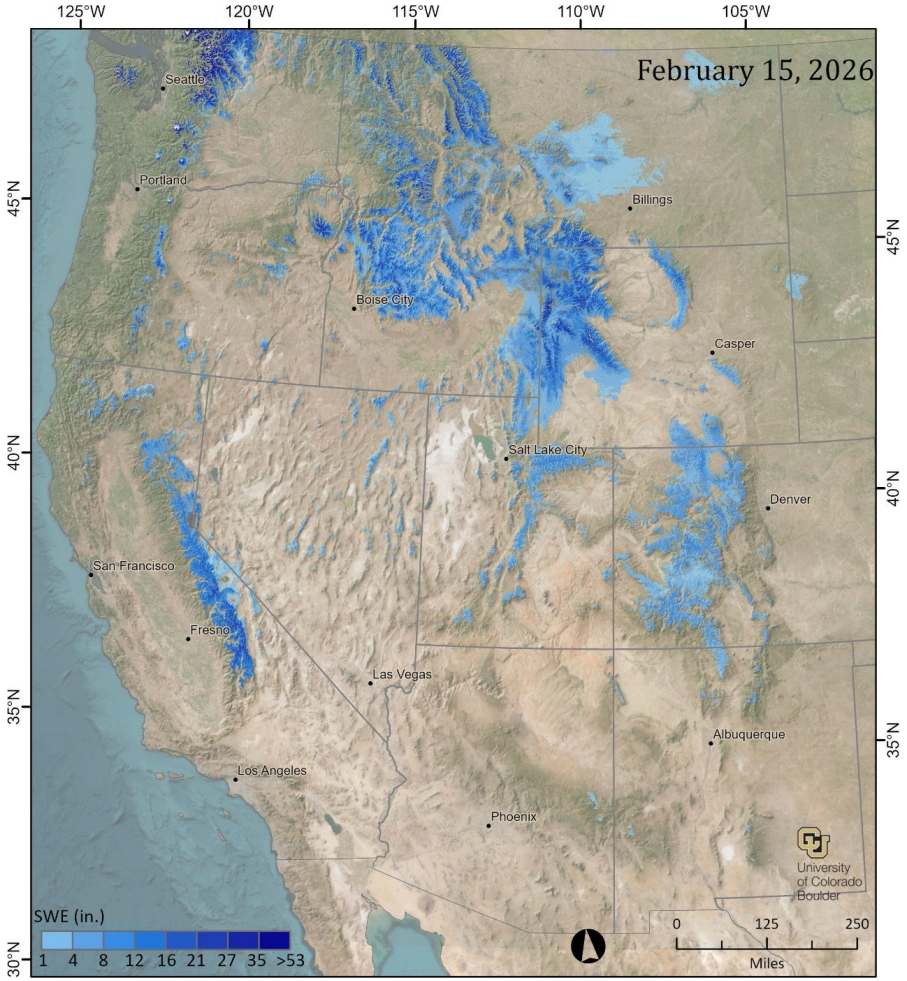


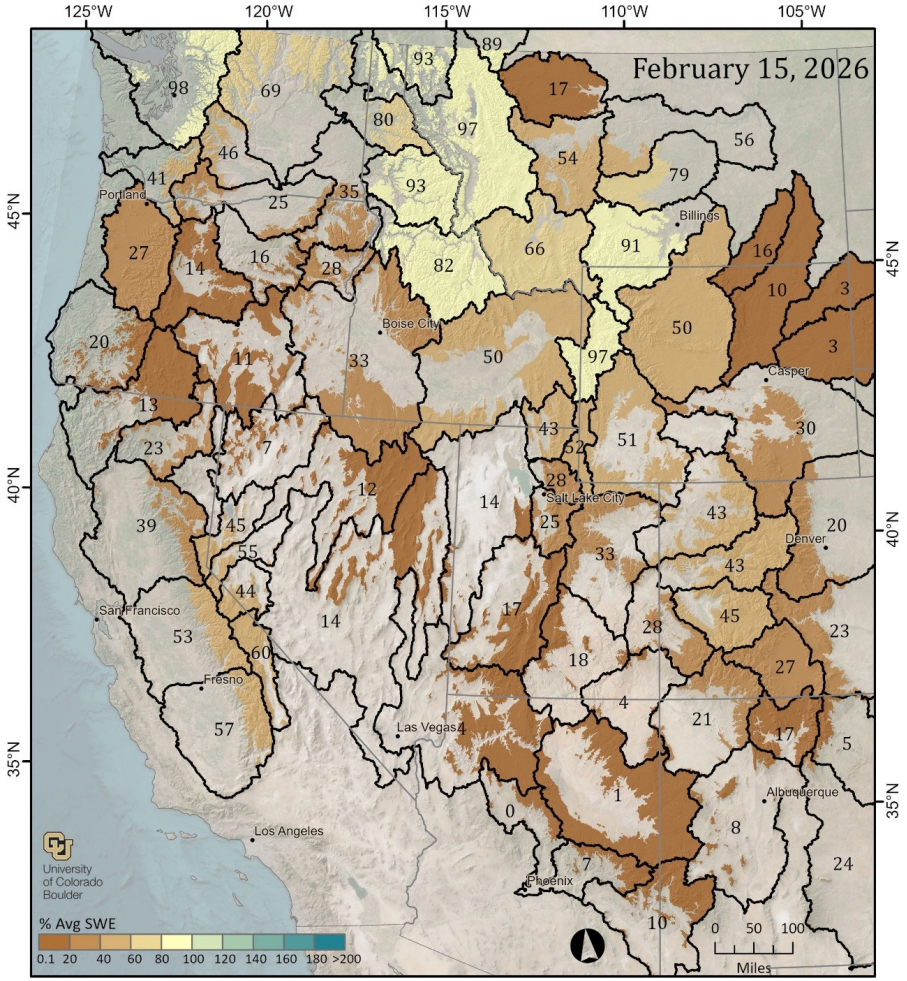
SWE-Fusion: Western US February 1, 2026



Source: INSTAAR Mountain Hydrology: Noah Molotch

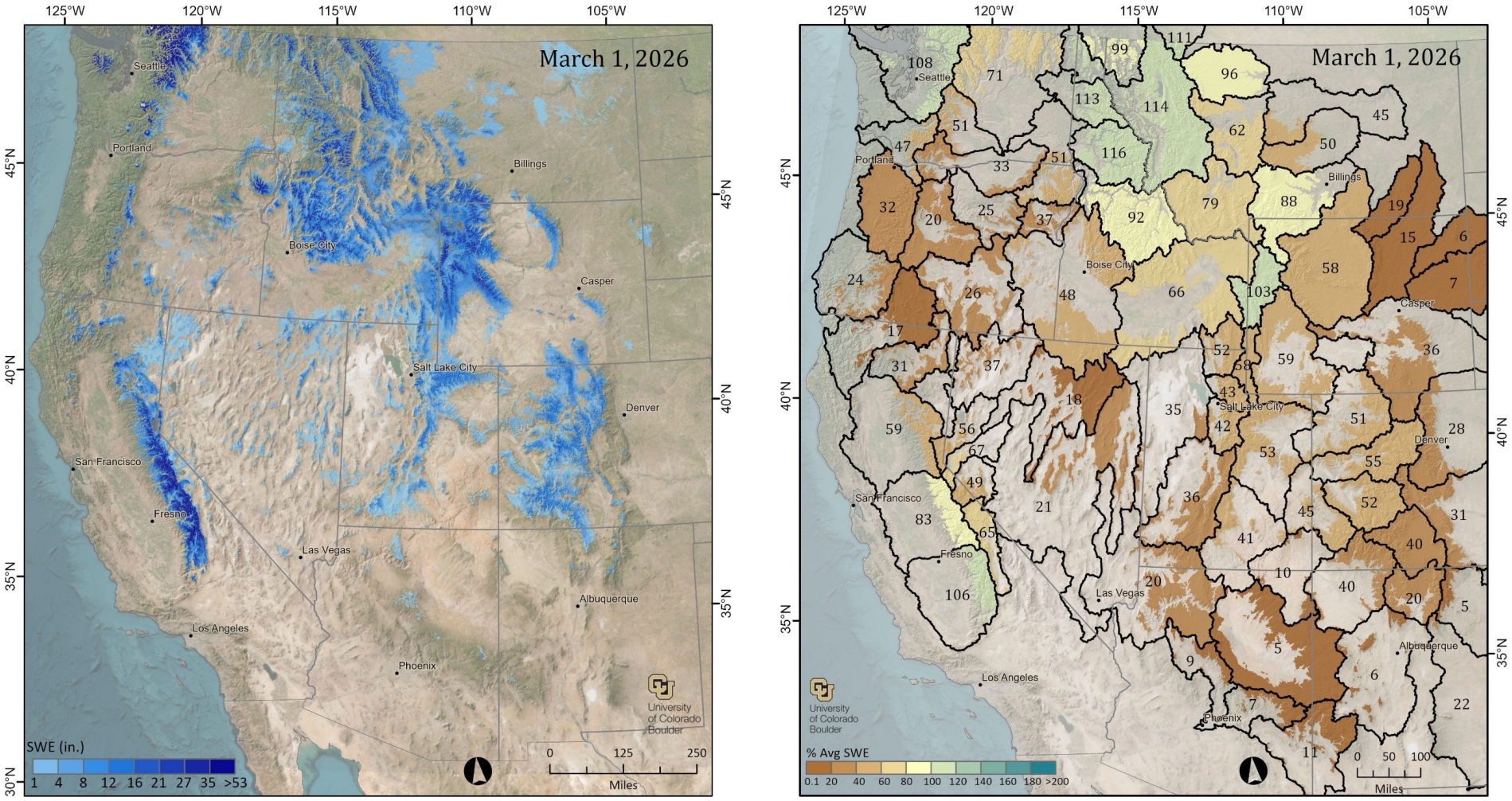
SWE-Fusion: Western US February. 15, 2026





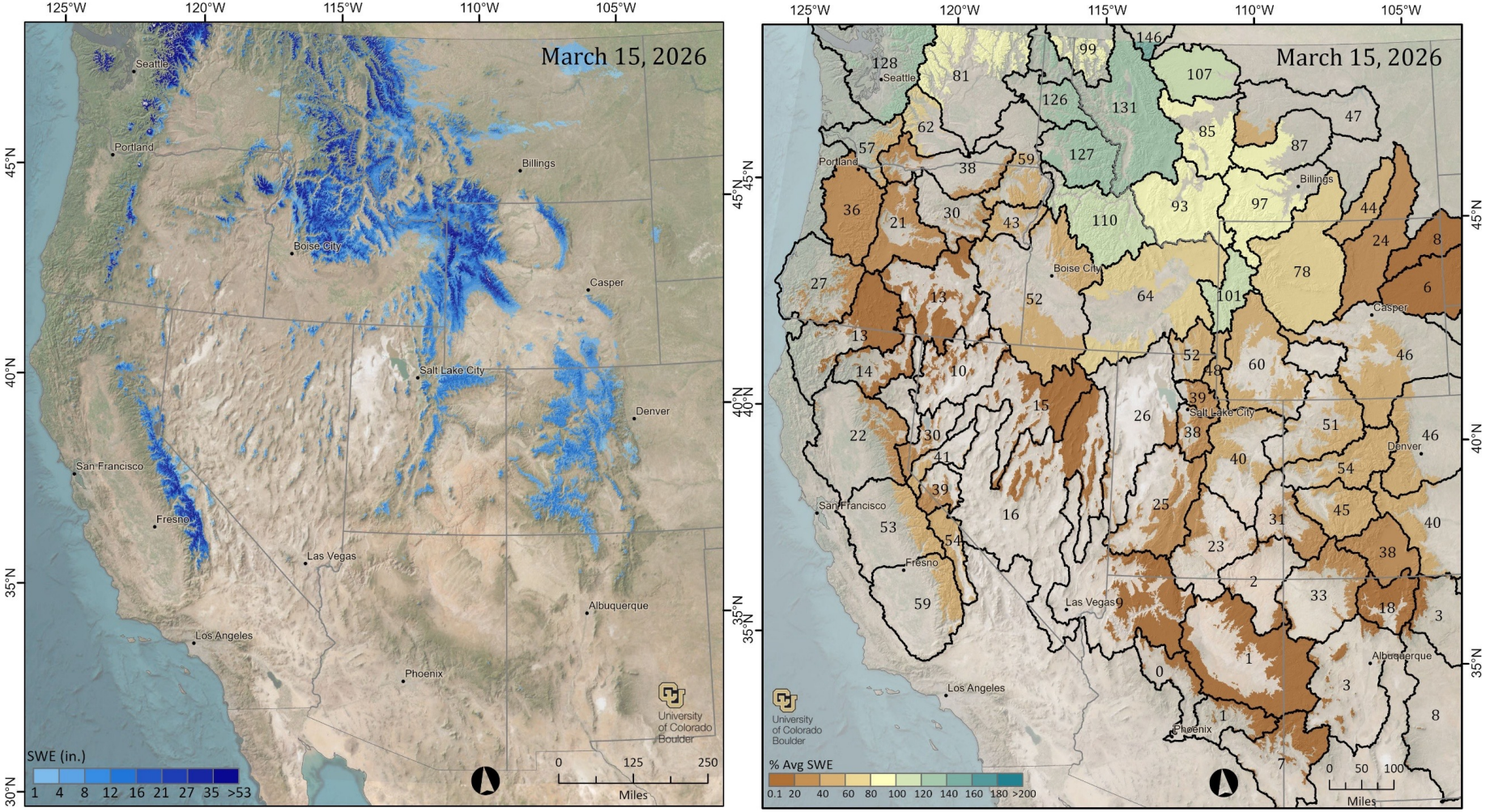
Source: INSTAAR Mountain Hydrology: Noah Molotch

SWE-Fusion: Western US March 1, 2026



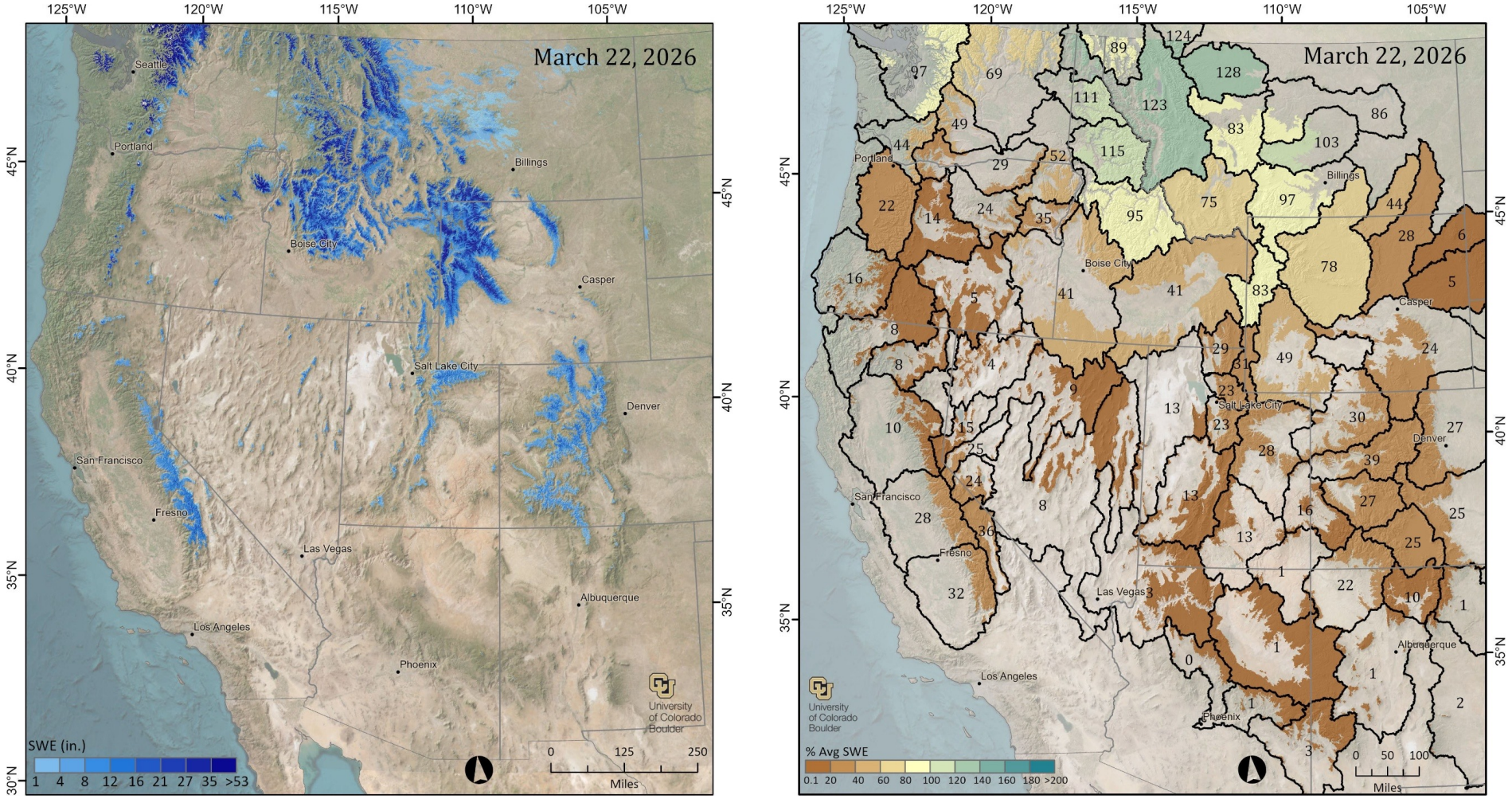
Source: INSTAAR Mountain Hydrology: Noah Molotch

SWE-Fusion: Western US March 15, 2026



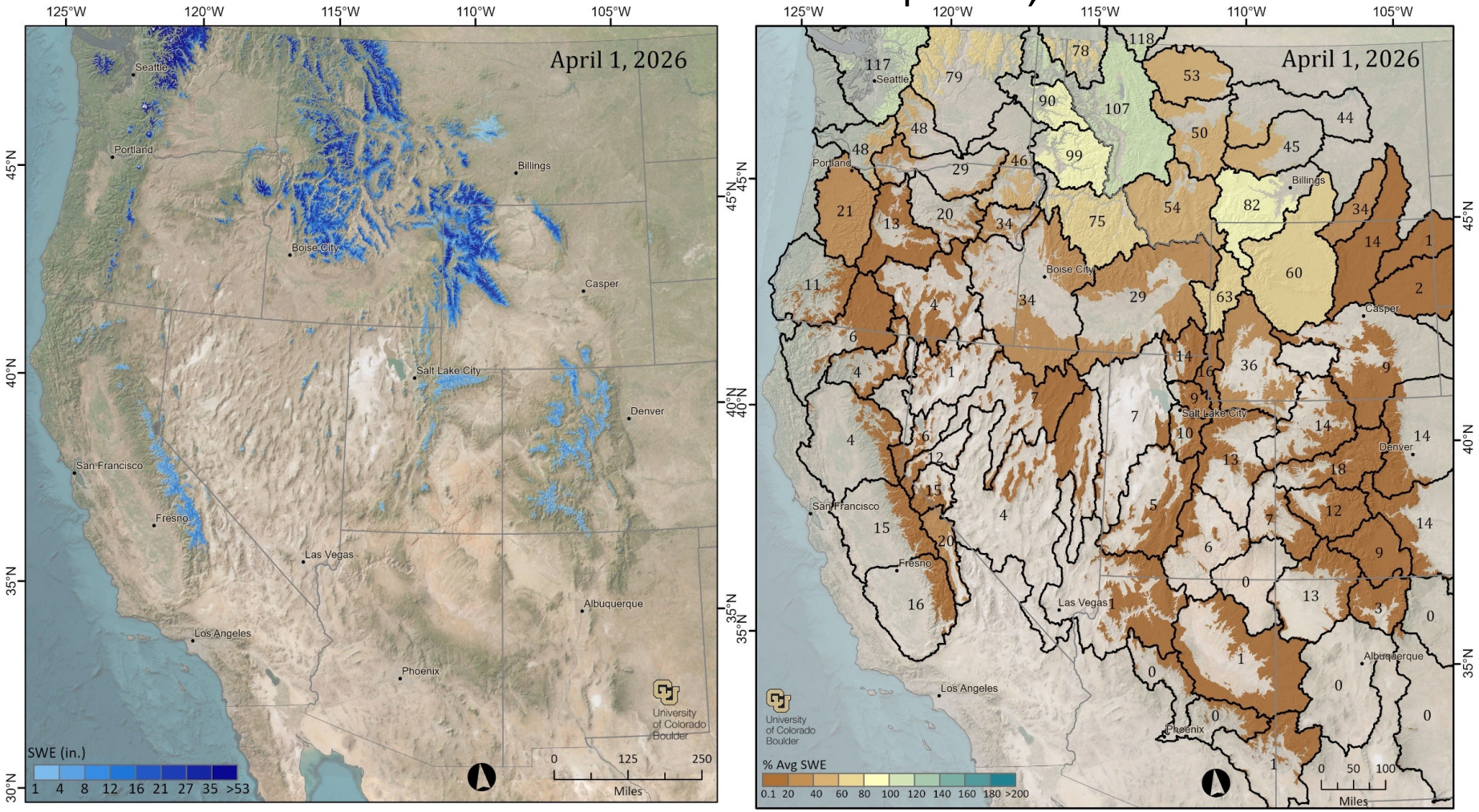
Source: INSTAAR Mountain Hydrology: Noah Molotch

SWE-Fusion: Western US March 22, 2026



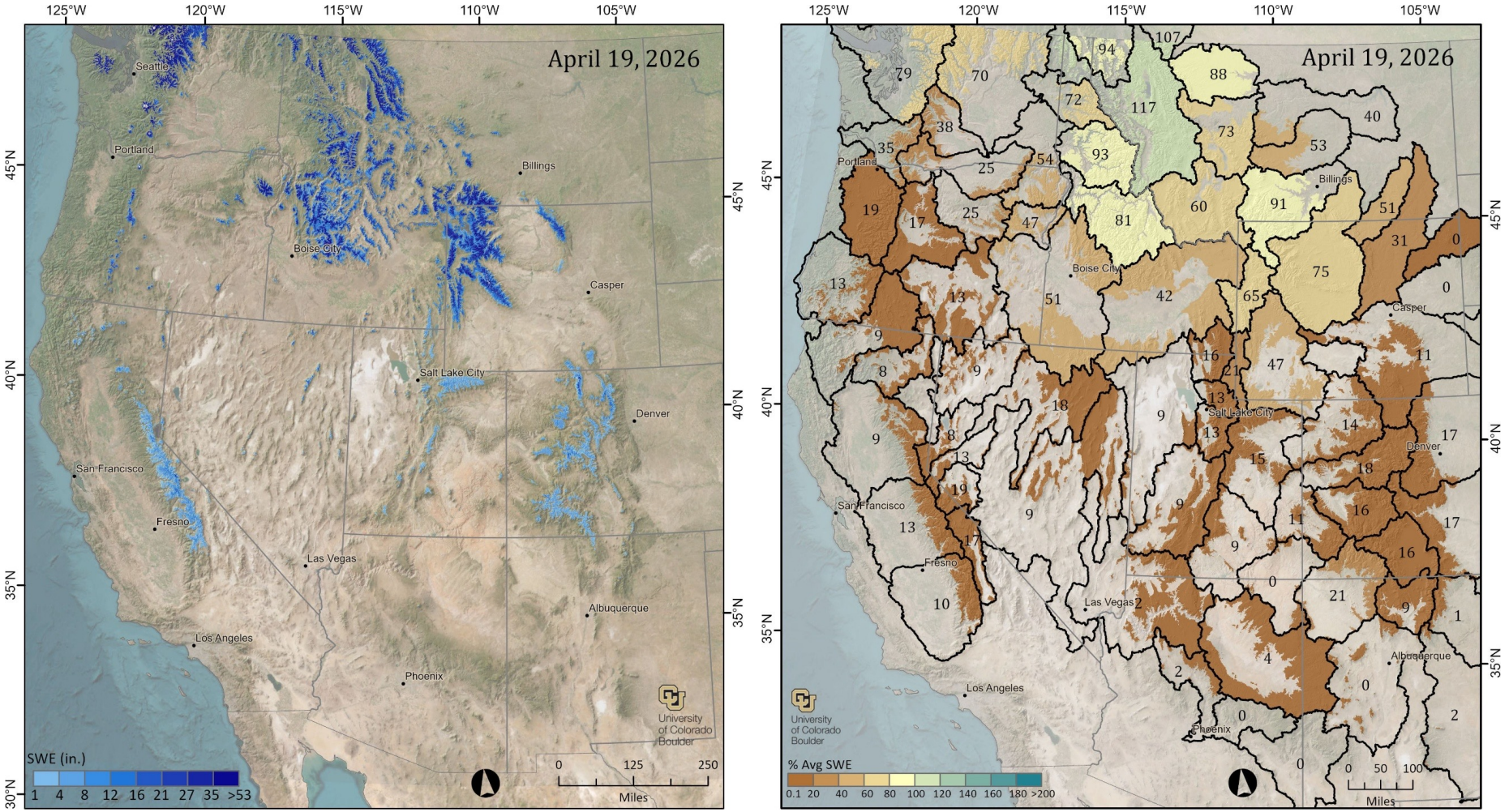
Source: INSTAAR Mountain Hydrology: Noah Molotch

SWE-Fusion: Western US April 1, 2026



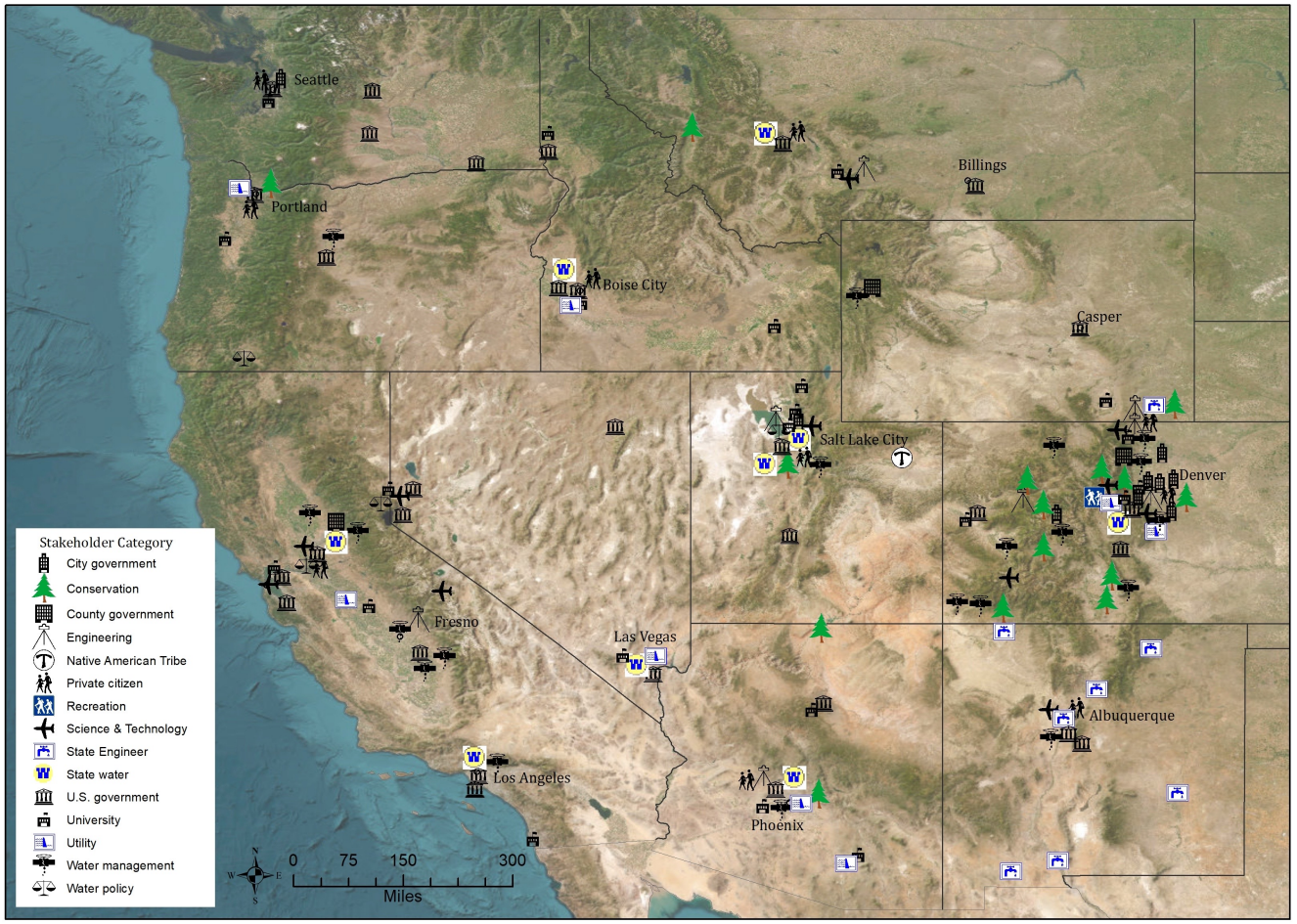
Source: INSTAAR Mountain Hydrology: Noah Molotch (noah.molotch@colorado.edu)

SWE-Fusion: Western US April 1, 2026



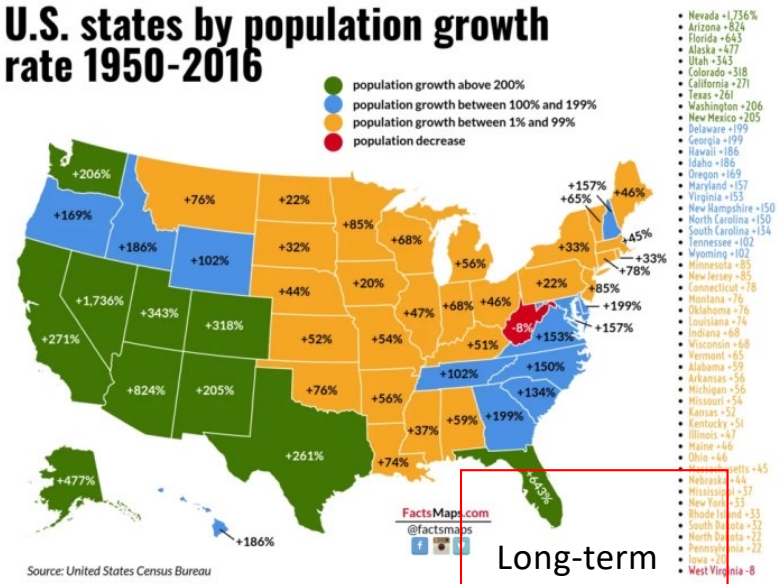
Real-Time SWE Stakeholder Engagement

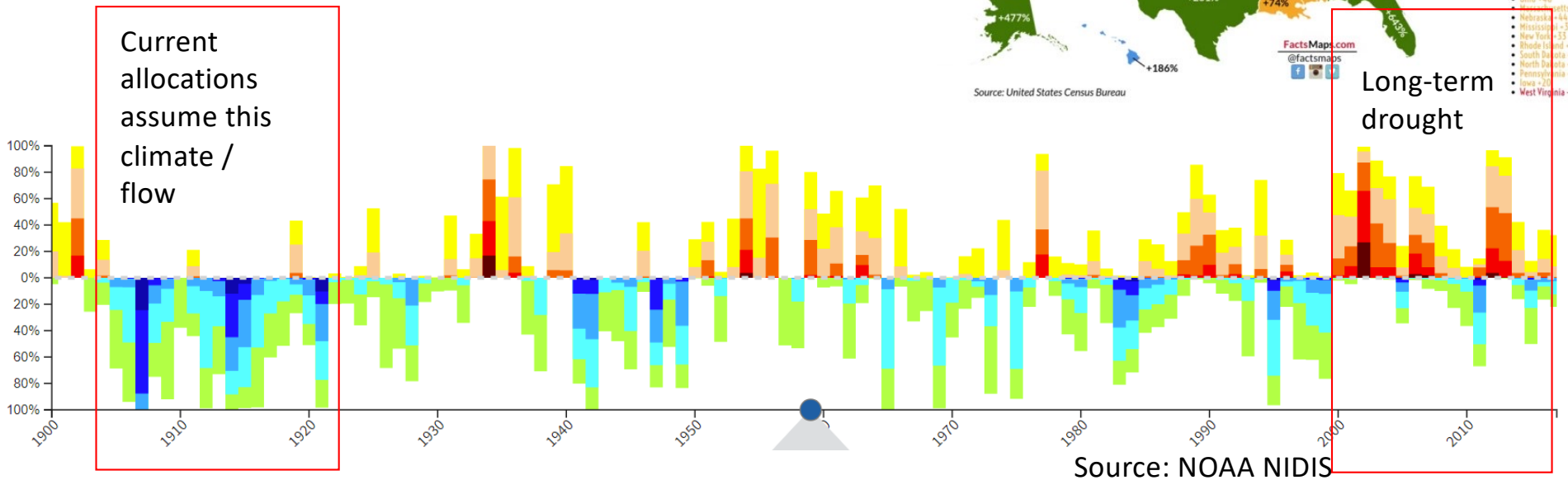
- **Hundreds of end-users have been involved in the development of SWE-Fusion**
- **Direct "users" of the SWE data include CA-DWR, CBRFC, CNRFC, NRCS, Reclamation**
- **Users are tracked based on feedback they provide and the data they utilize**
- **Data users vary from qualitative assessment to use of gridded data**



Lessons from the 2026 Snow Drought: Current Conditions

- Notice relatively wet period in first half of century.
- Relatively neutral conditions 1950-2000
- Dry conditions 2000 - present

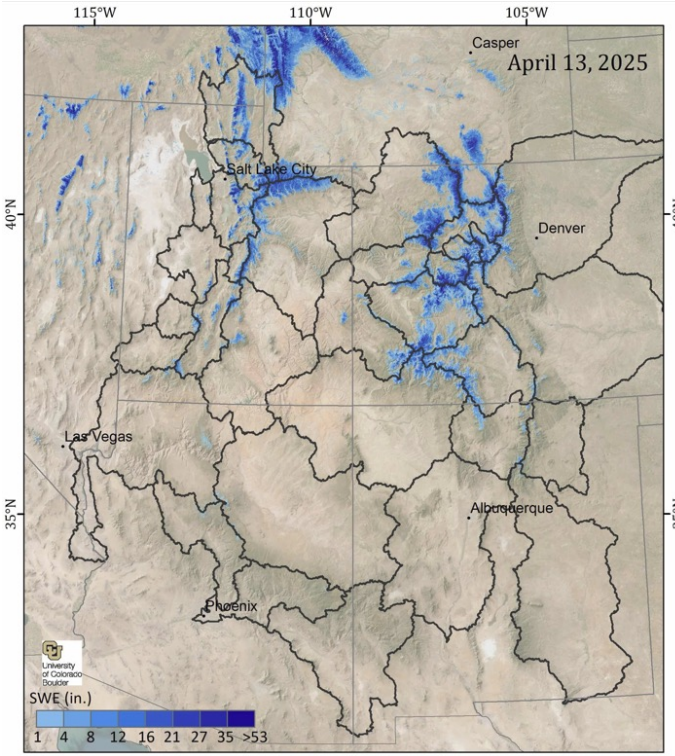




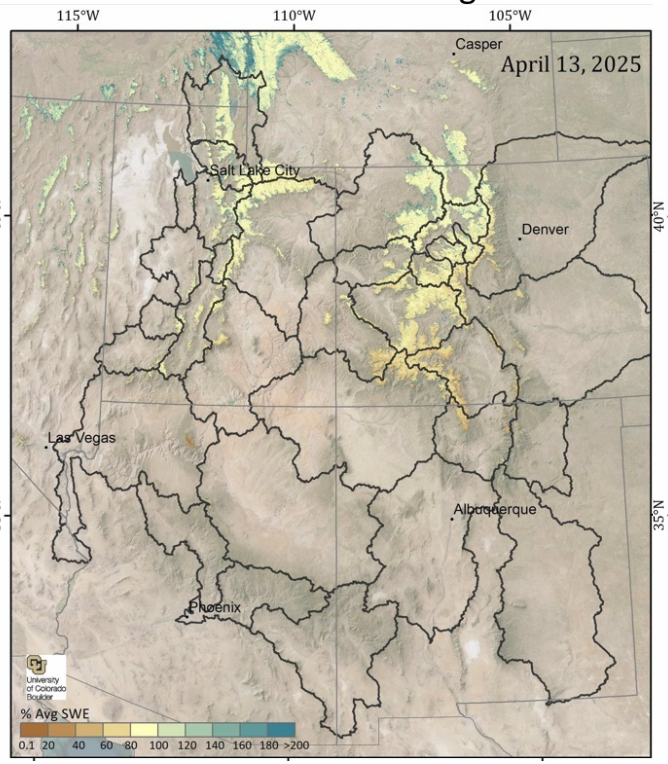
Source: NOAA NIDIS

SWE-Fusion: Colorado River Basin Drought April 13, 2025

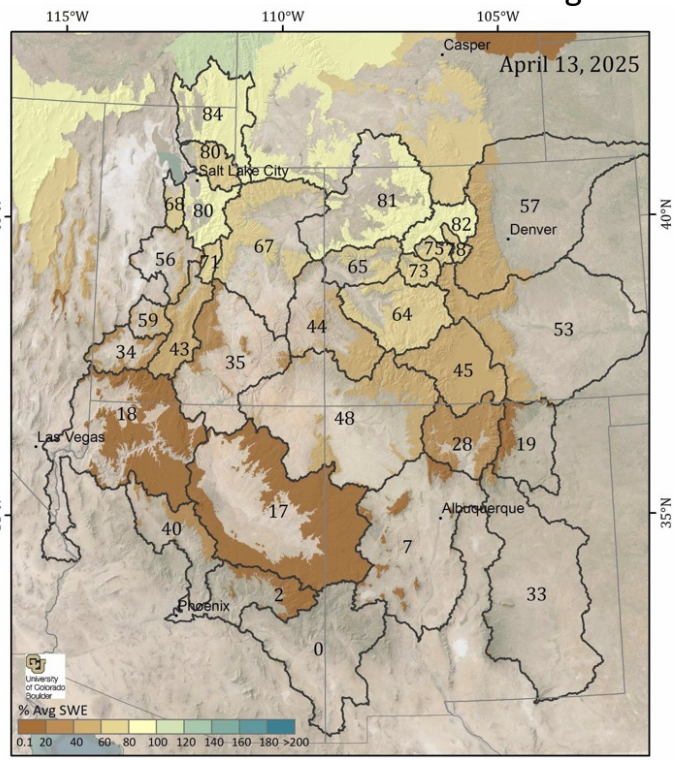
Snow Water Equivalent



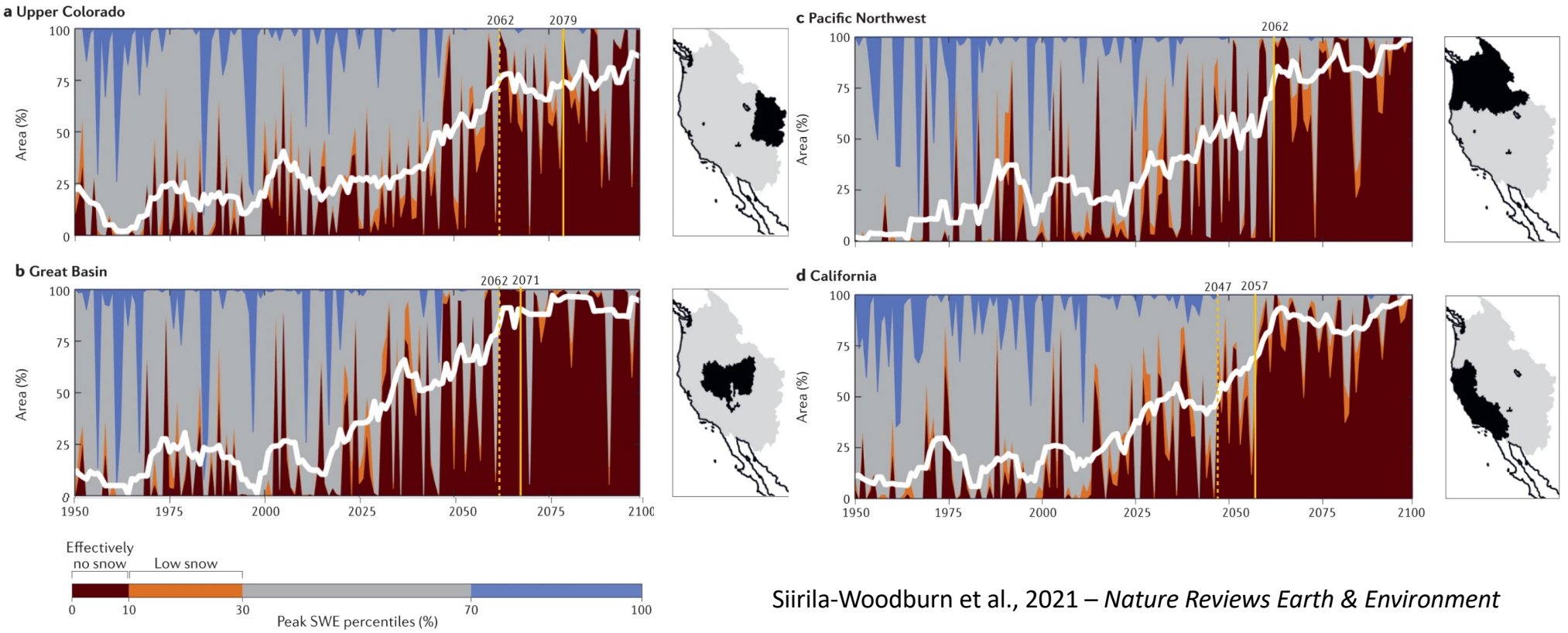
Pixel Percent of Average



Watershed Percent of Average

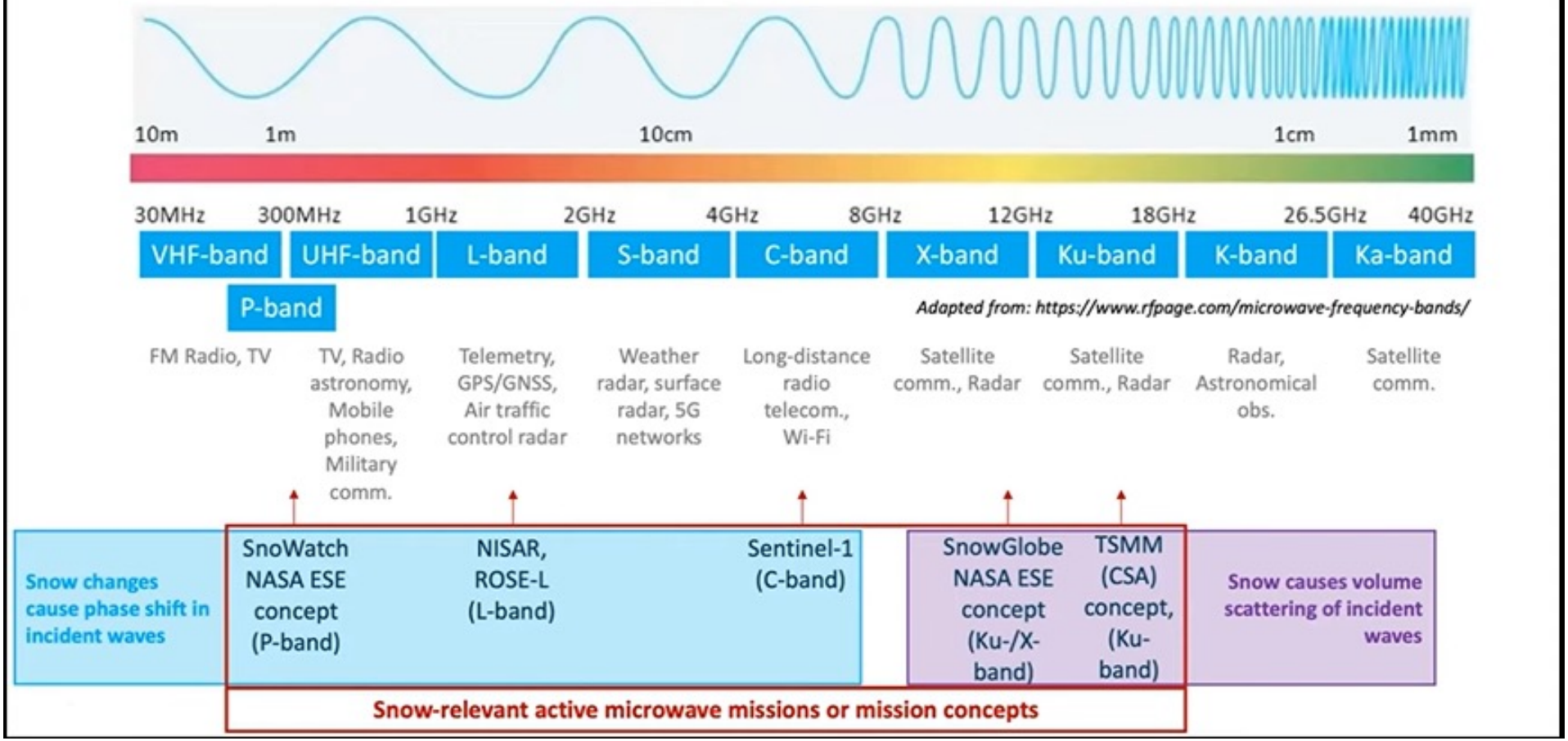


Lessons from the 2026 Snow Drought: The Future



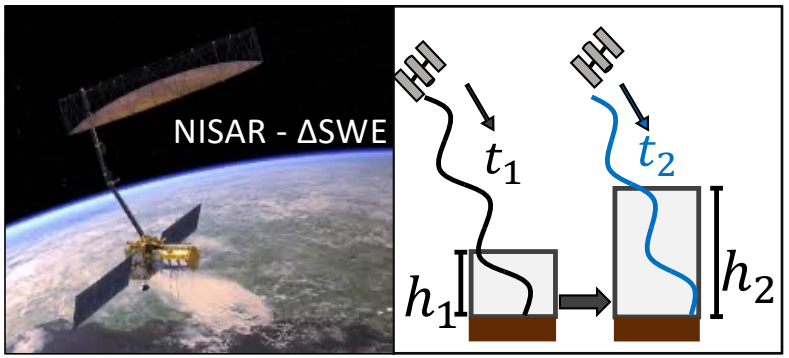
Siirila-Woodburn et al., 2021 – *Nature Reviews Earth & Environment*

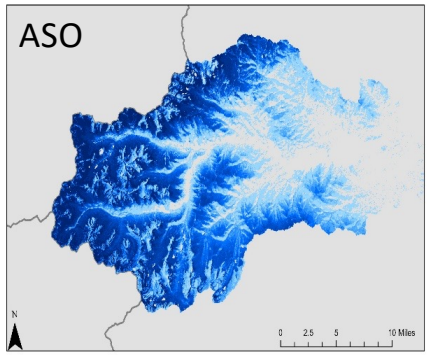
Microwave wavelengths useful for SWE retrievals



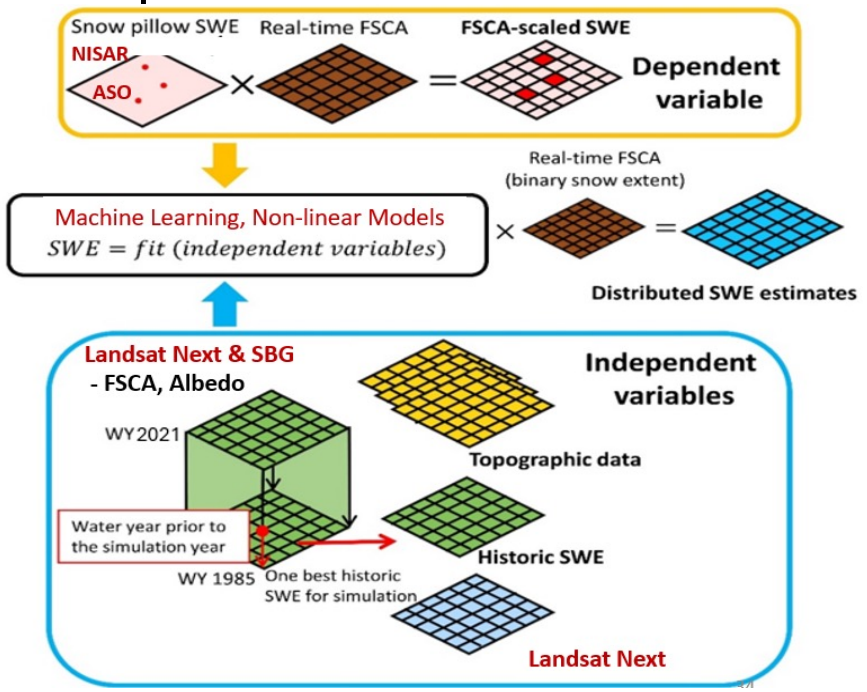
Source: Steve Margulis, UCLA

Future Directions: NISAR, ML, & EAGLE Information Systems





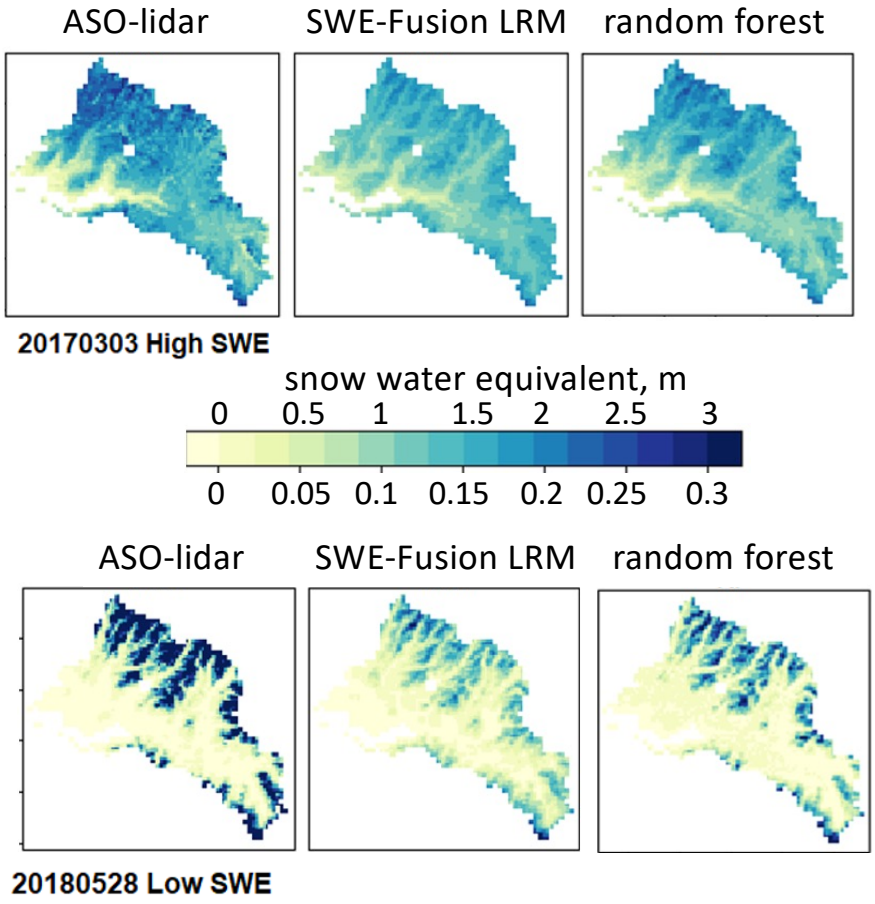
- Train model on NISAR and ASO data.
- Utilize larger training sample size in Deep Learning Models
- Integrate data into Snow Water Equivalent Dashboards / Information Systems: e.g. CA DWR SnowTrax, USBR, SnowToday

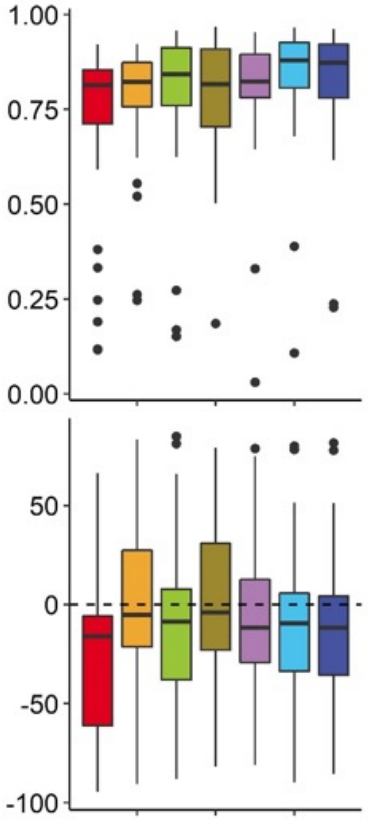


Conclusions

- The current snow drought in the Colorado River Basin is particularly concerning given the multi-year drought, record low reservoir storage, and general over-allocated nature of the basin.
- A common characteristic of snow drought is earlier snowmelt which may lead to overall reductions in runoff efficiency & increased fire risk.
- Snow droughts represent a prime example of established non-stationarities in climate and hydrologic conditions which challenge conventional water supply forecasts.
- New approaches for measuring SWE from aircraft (e.g. ASO), satellite (e.g. TSMM, NISAR, future mission?), and ground-based platforms are essential as the climate changes.
- Data fusion-approaches such as those highlighted here, are transforming water management by providing insights into the physical mechanisms that govern runoff response to anomalous hydrologic conditions such as snow droughts.

Bias-Correcting SWE-Fusion w/ the Airborne Snow Observatory lidar





- LRM
- Linear Scale
- Gaussian Process Regression
- Bidirectional Recurrent Neural Networks
- Support vector machine
- Random Forest
- Gradient Boosting Machine

	R^2	PBIAS (%)	ABS PBIAS (%)
LRM	0.70	-27	33
LS	0.77	-11	25
GPR	0.78	-11	21
BRNN	0.78	-9	20
SVM	0.79	-12	21
RF	0.83	-12	20
GBM	0.82	-12	20

Yang et al., Remote Sensing of Environment, 2025

SWE-Fusion: Western US Jan. 15, 2025