Advancing Probabilistic Snowfall Prediction in the Mountain West and Beyond

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NOAA/ESRL

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WPC

Randy Chase, CoCoRAHS Team
Colorado State University

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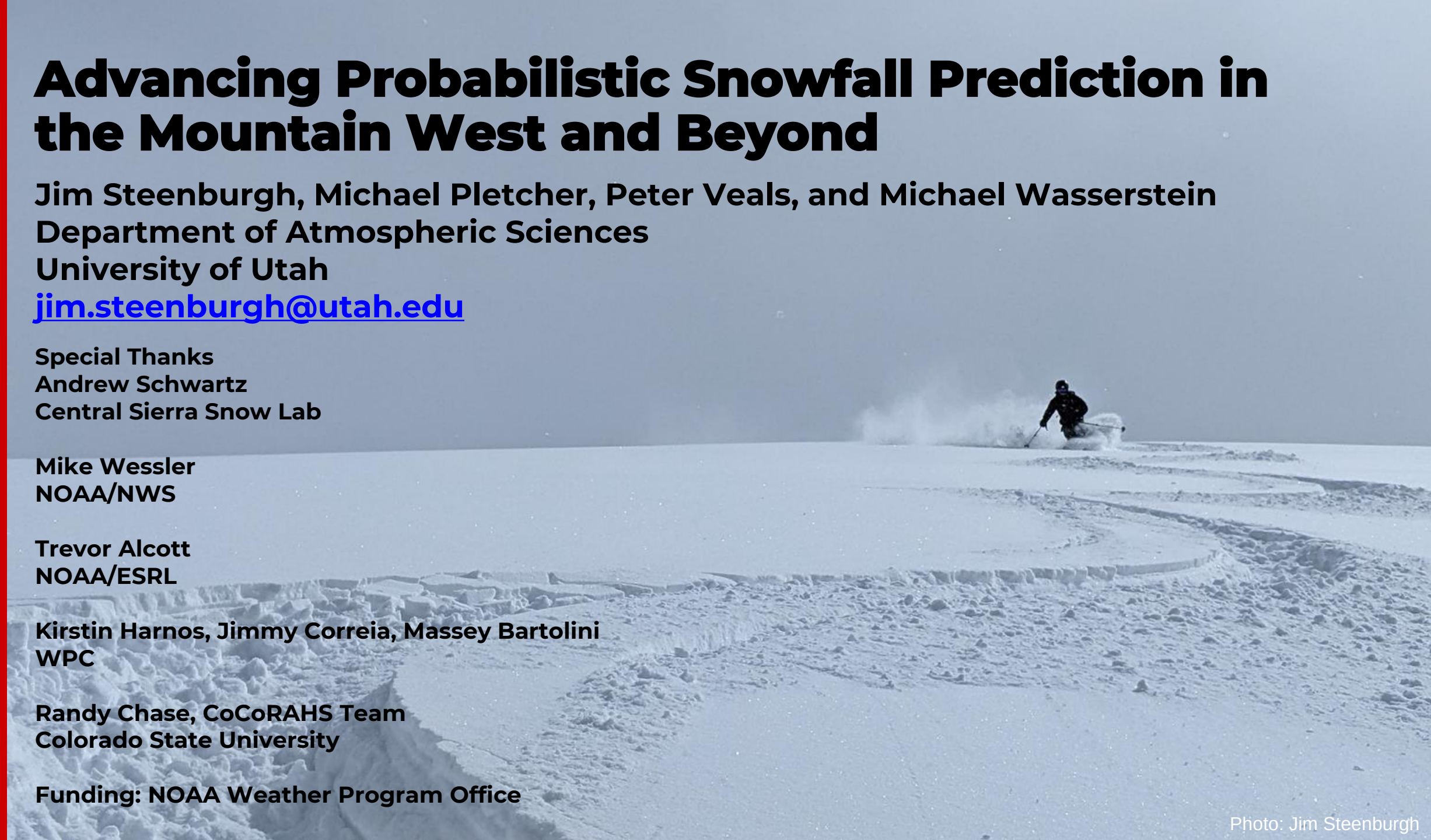


Photo: Jim Steenburgh

Trevor Alcott

Mike Wessler

Peter Veals

Michael Pletcher

Michael Wasserstein

This began as an organic project!

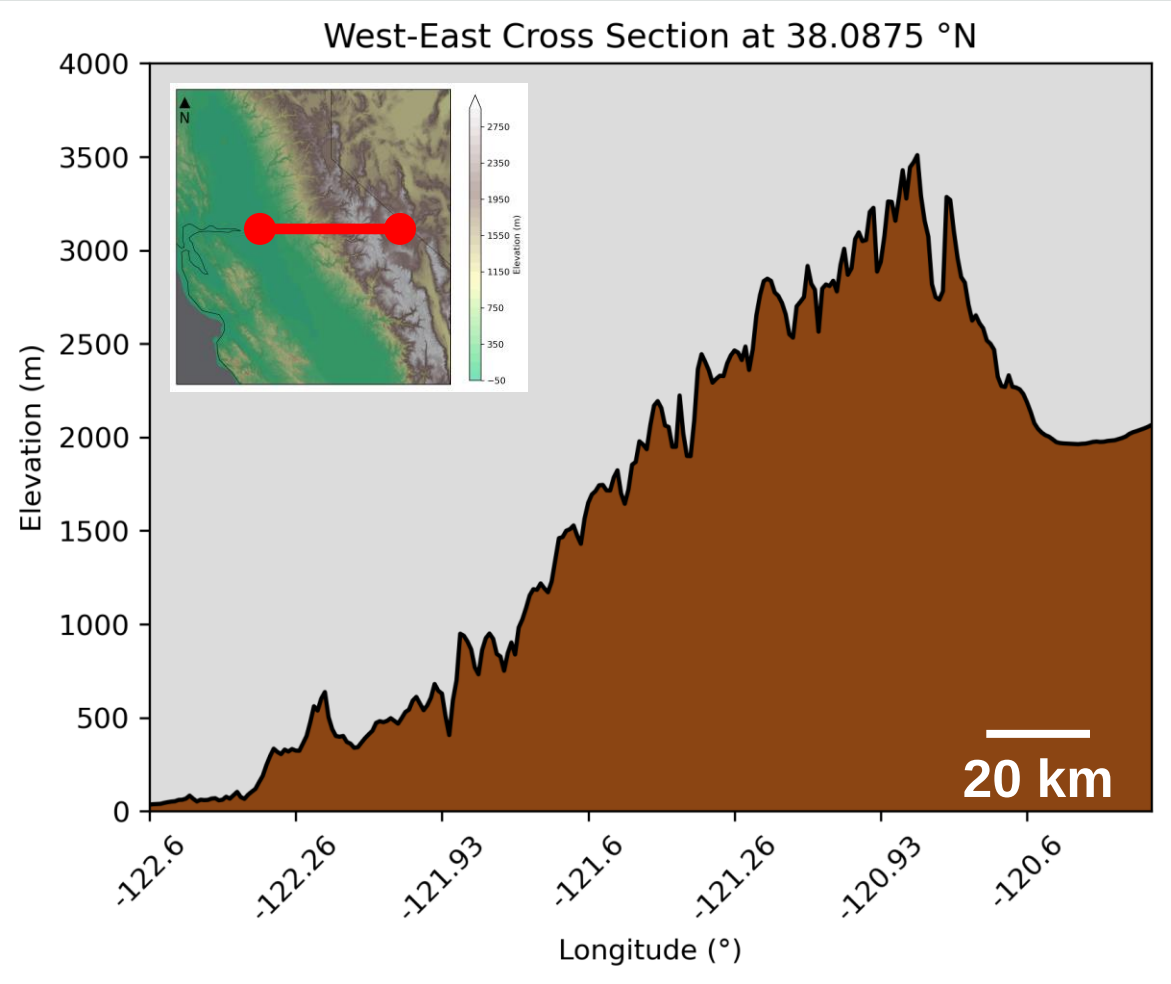
Portions remain a labor of love

Hat tip: NOAA Weather Program Office for snow-to-liquid ratio support

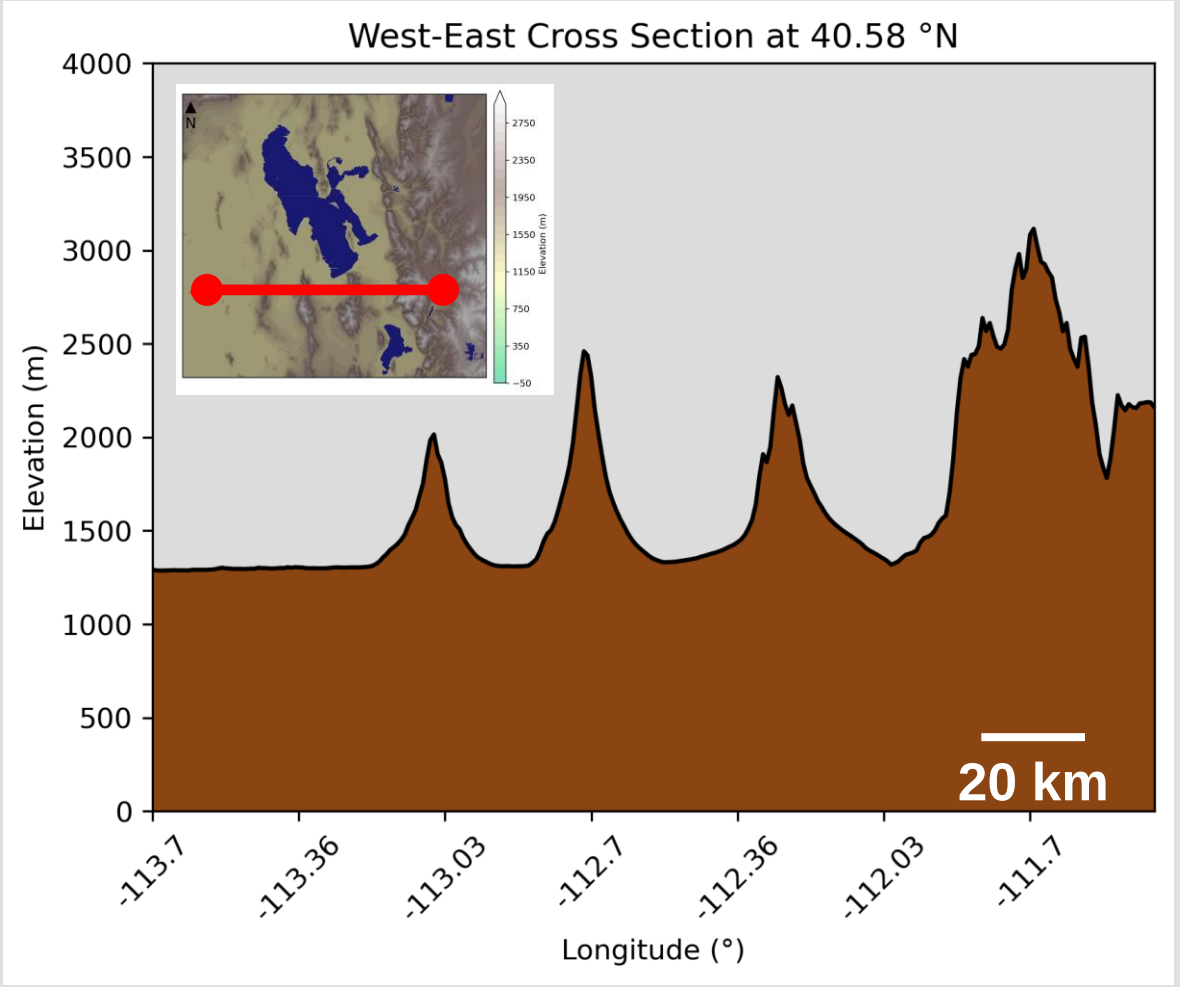
Motivation

- US operational NWP systems still inadequately resolve or account for precipitation and microphysical processes over the western CONUS
- Especially true for medium-range forecast guidance, but also an issue for detailed short-range prediction in fine-scale orography
- Snow-to-liquid ratio is also a challenge
- Issues are especially acute over the Great Basin

Wide vs. Fine-Scale Orography

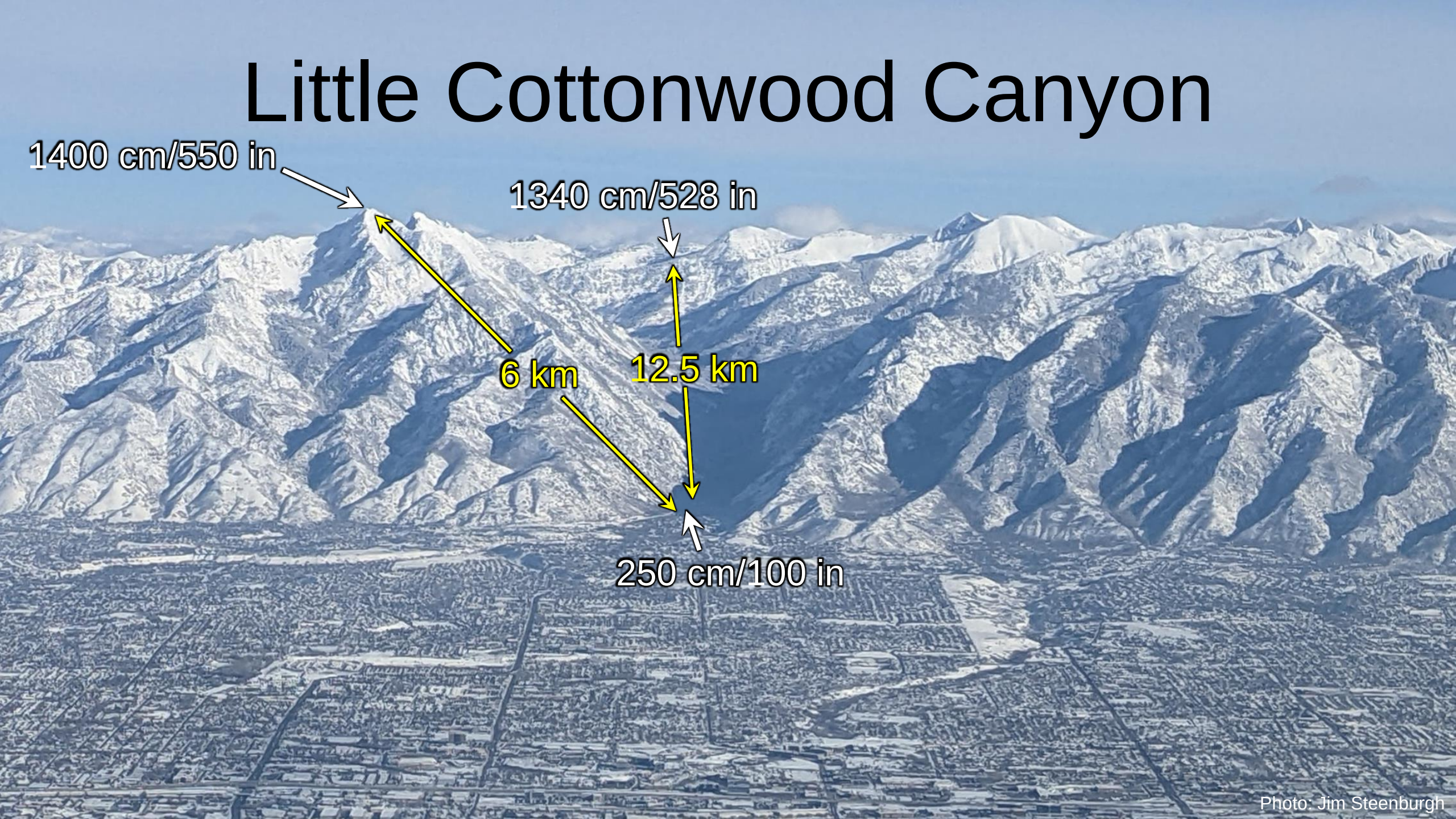


Sierra Nevada

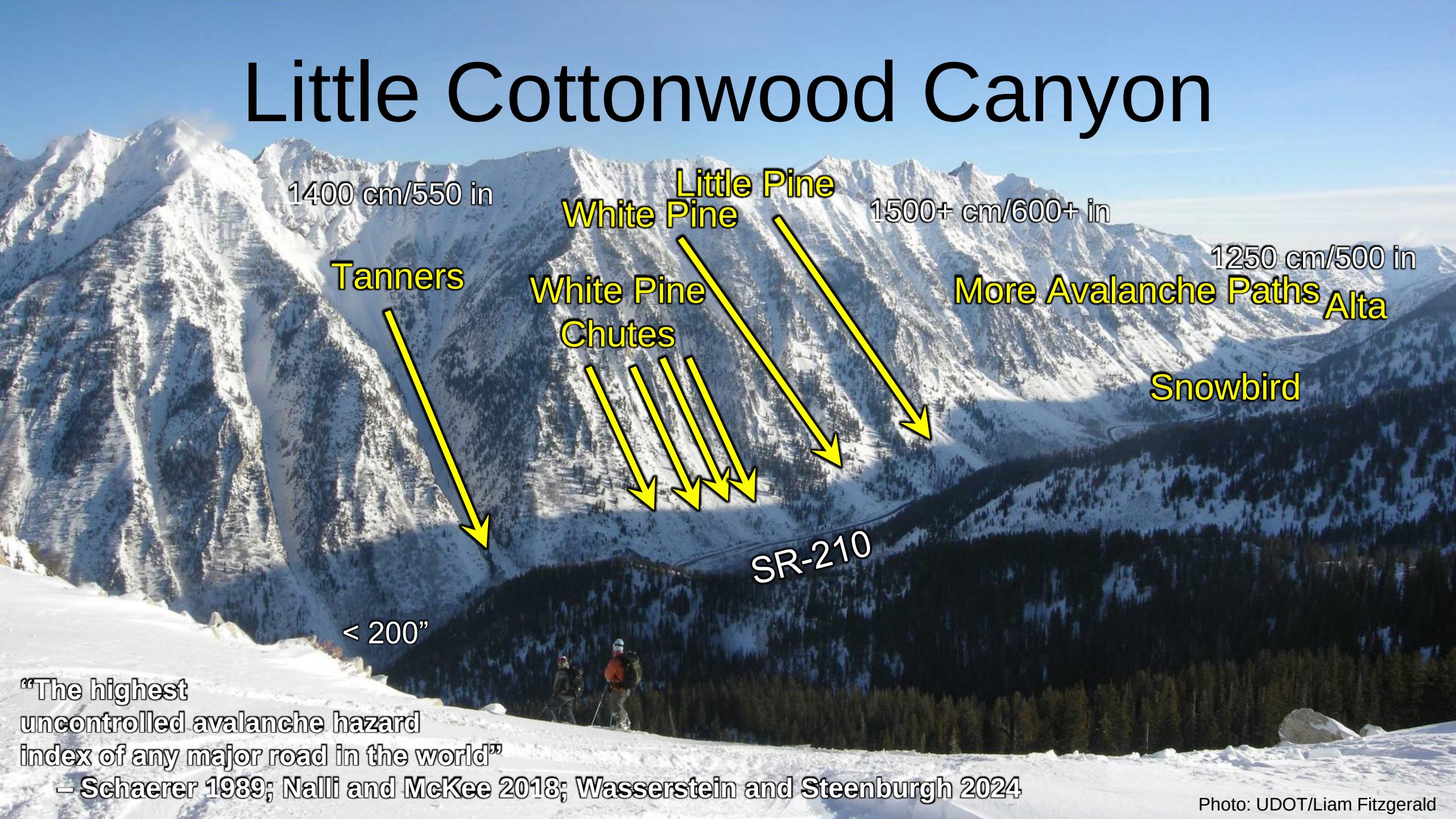


Northern Utah

Little Cottonwood Canyon



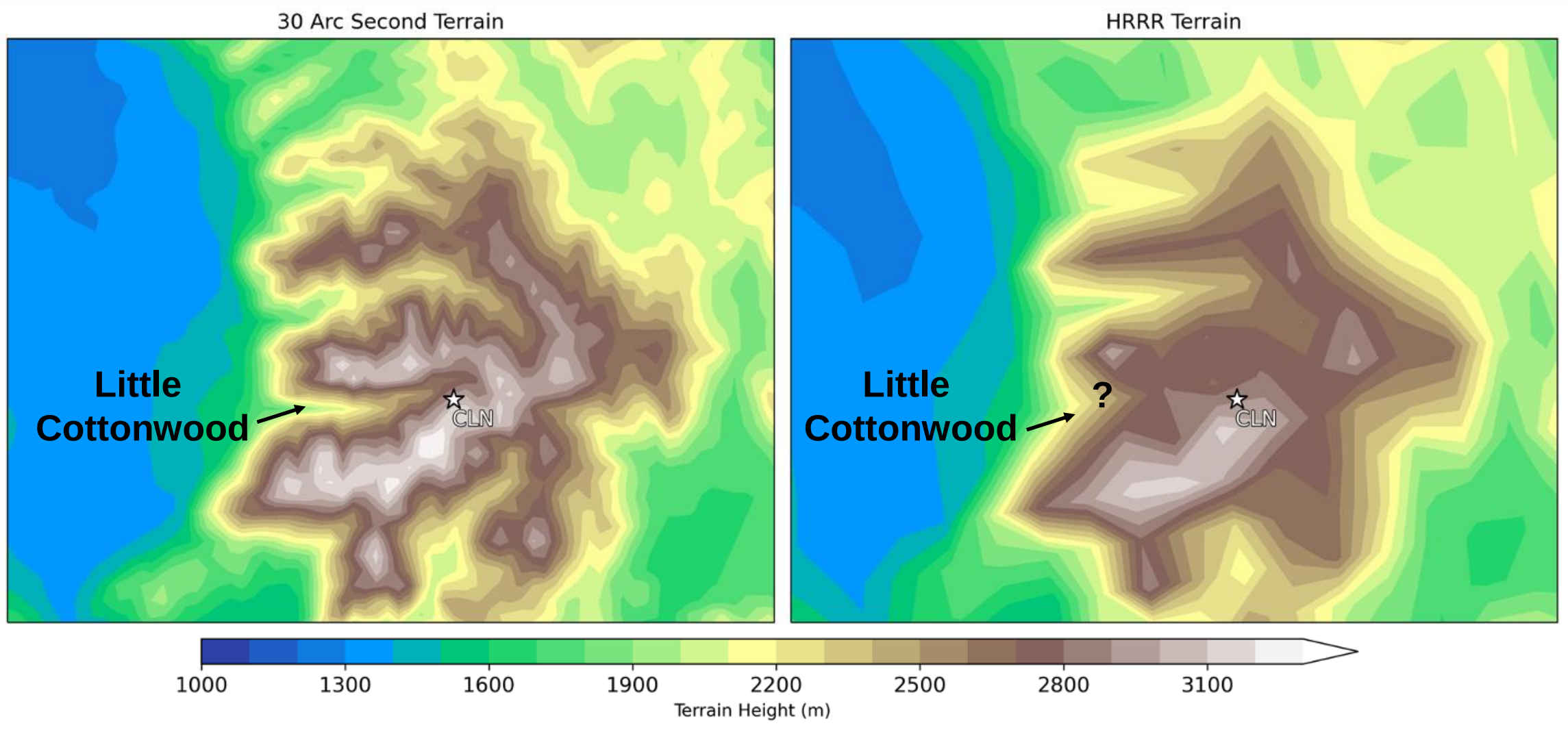
Little Cottonwood Canyon



“The highest uncontrolled avalanche hazard index of any major road in the world”
– Schaerer 1989; Nalli and McKee 2018; Wasserstein and Steenburgh 2024

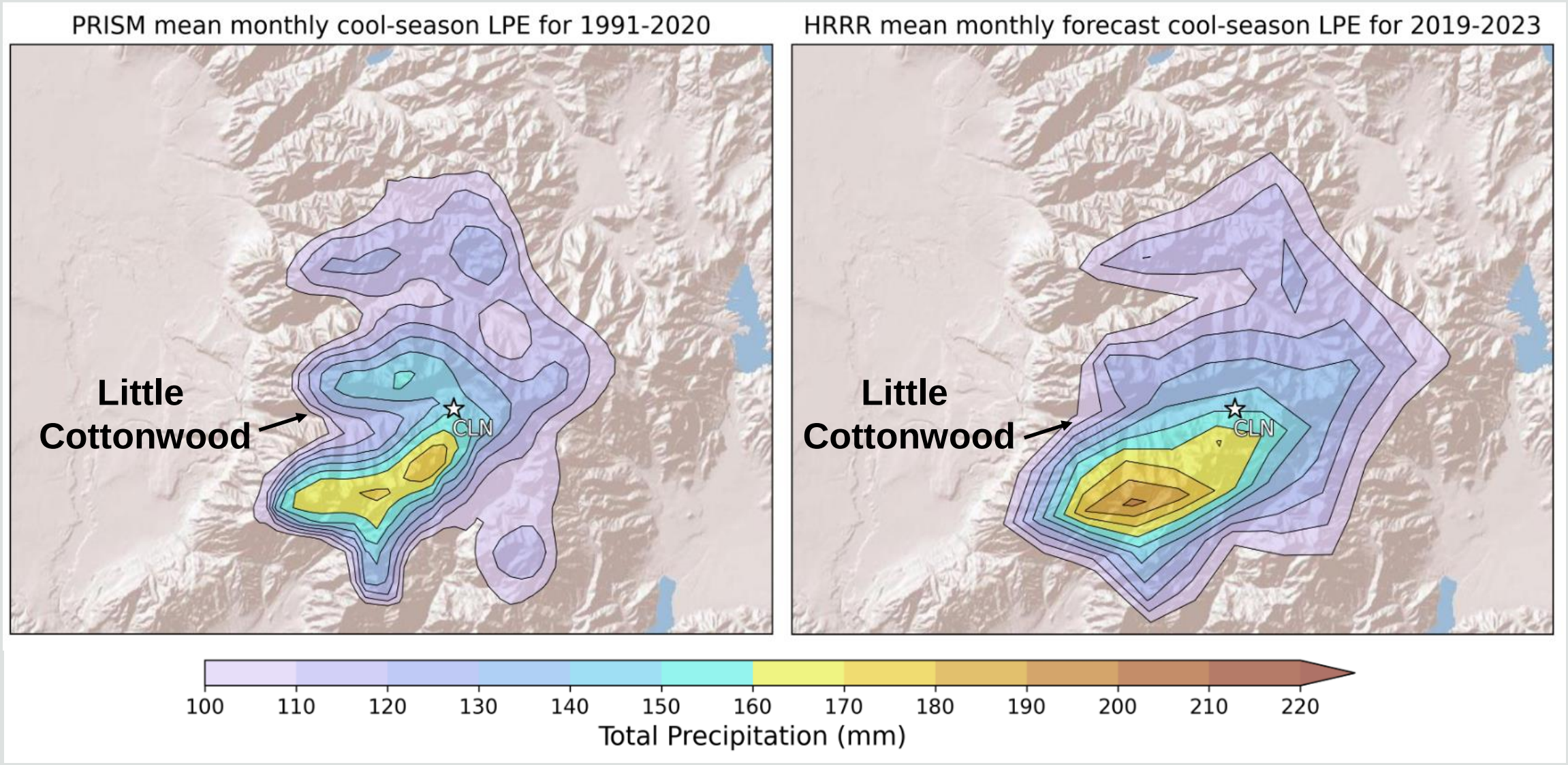
Photo: UDOT/Liam Fitzgerald

Terrain Representation



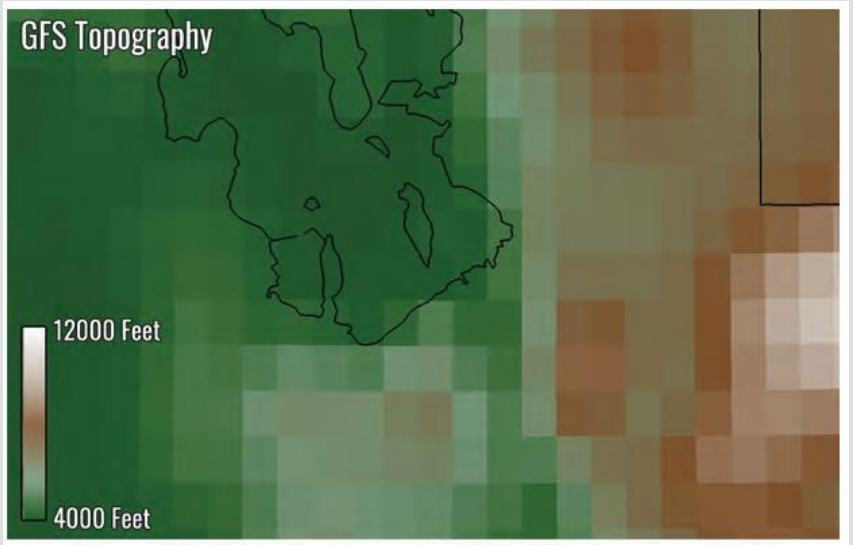
Courtesy Michael Wasserstein, University of Utah

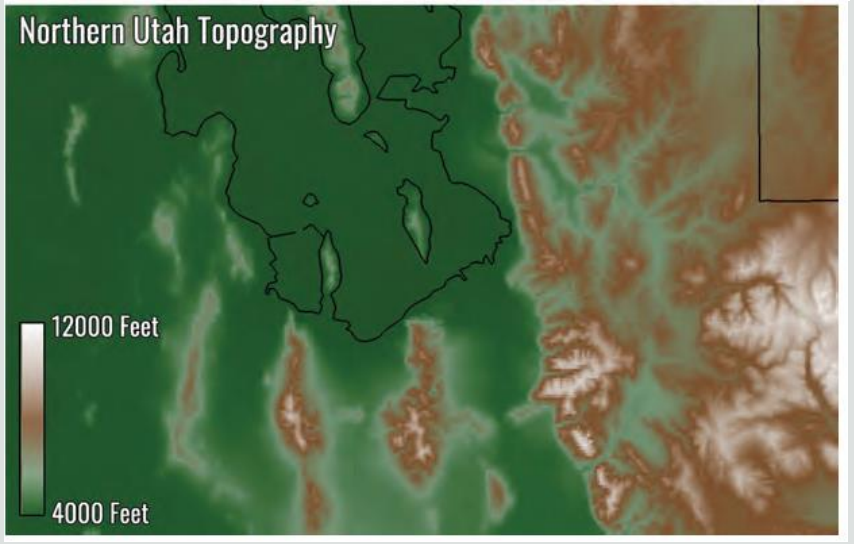
Impacts on Seasonal Precip



Courtesy Michael Wasserstein, University of Utah

GFS Anyone?

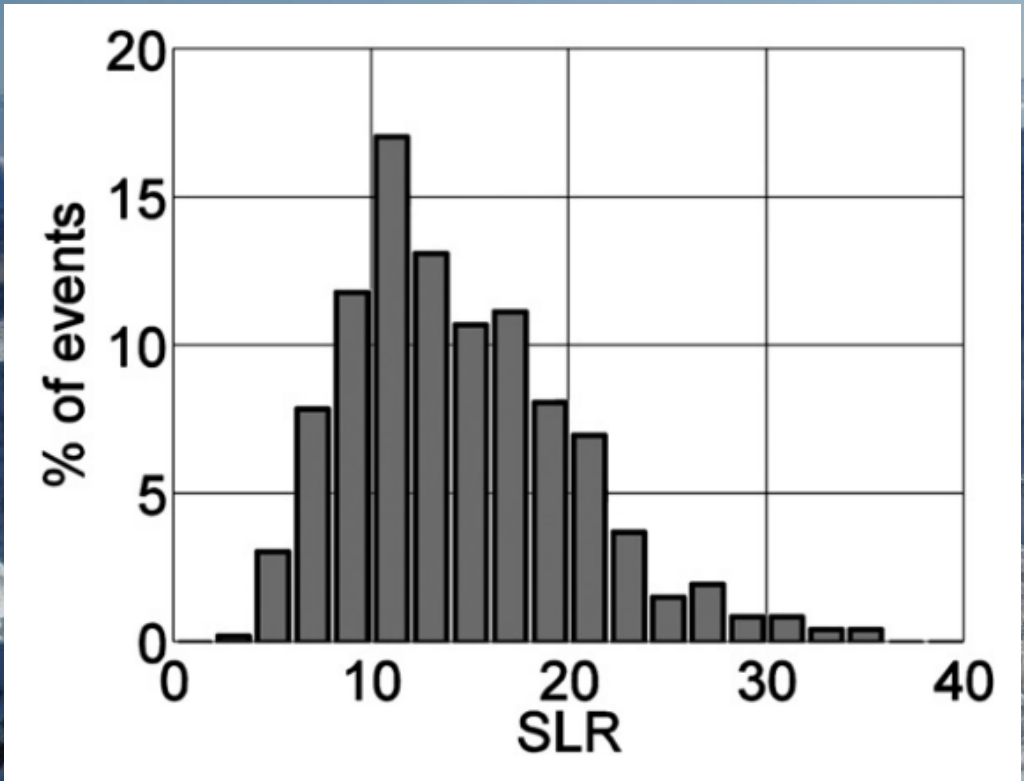




Issues worsen for GEFS/ECMWF ENS

Steenburgh 2023

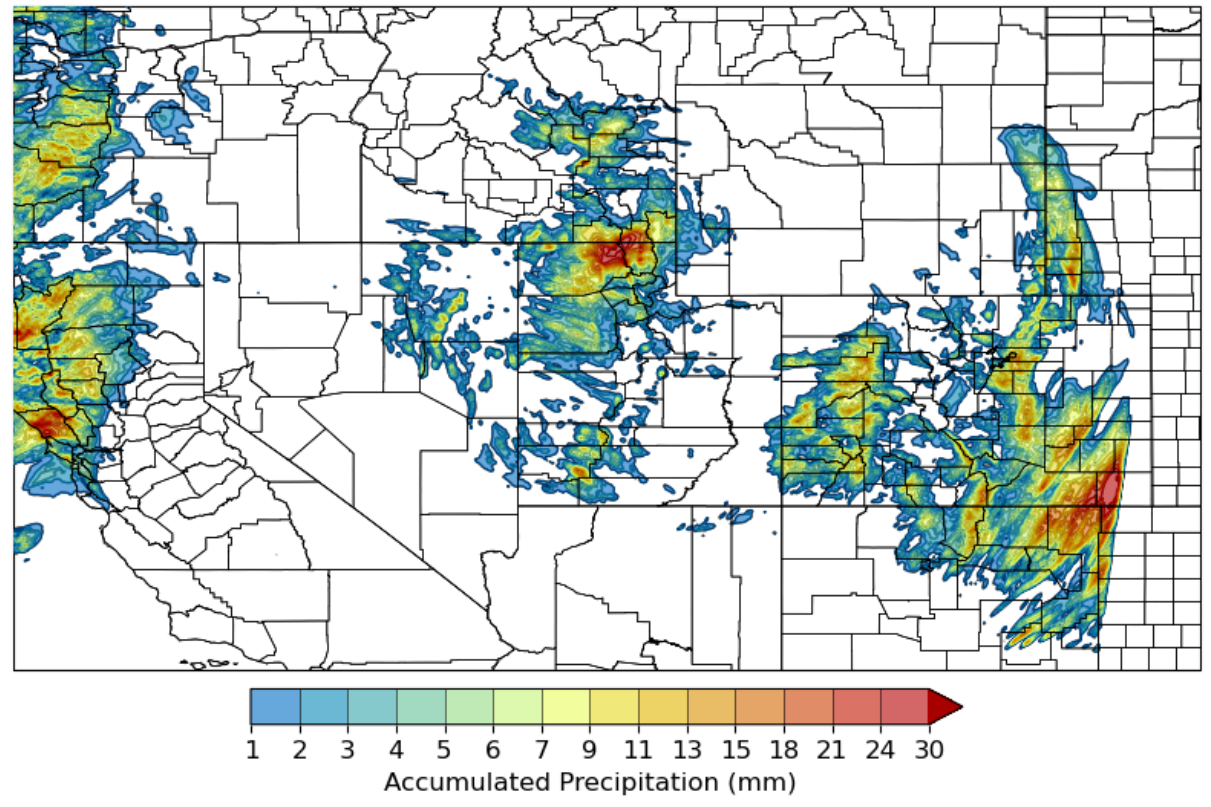
Snow-to-Liquid Ratio (SLR): Alta



- Median 13.3:1
- 25th percentile: 10:1
- 75th percentile: 18:1
- Range: 3.6-35.7

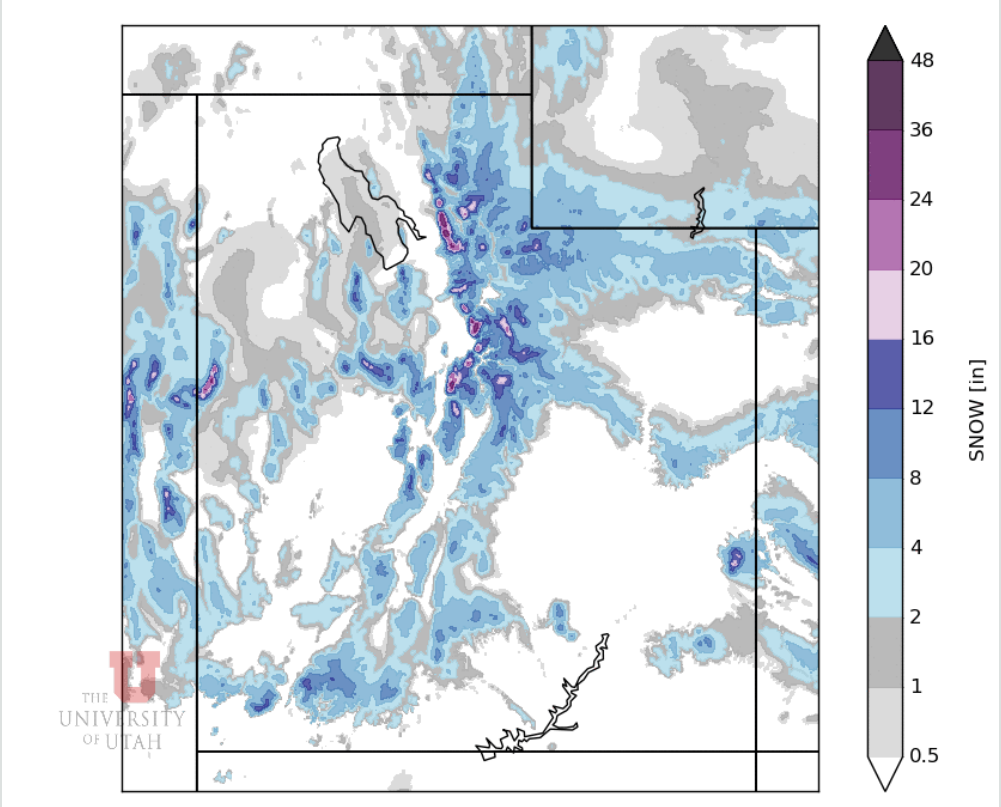
Stats/Image: Alcott and Steenburgh 2010; Photo: Jim Steenburgh

Options (Circa 2012)



High Res WRF

We've done this before
It's deterministic



Post-Processing

We haven't done this before
It's fast and can be applied to any model
It's potentially probabilistic

Step 1: Climatological Downscaling

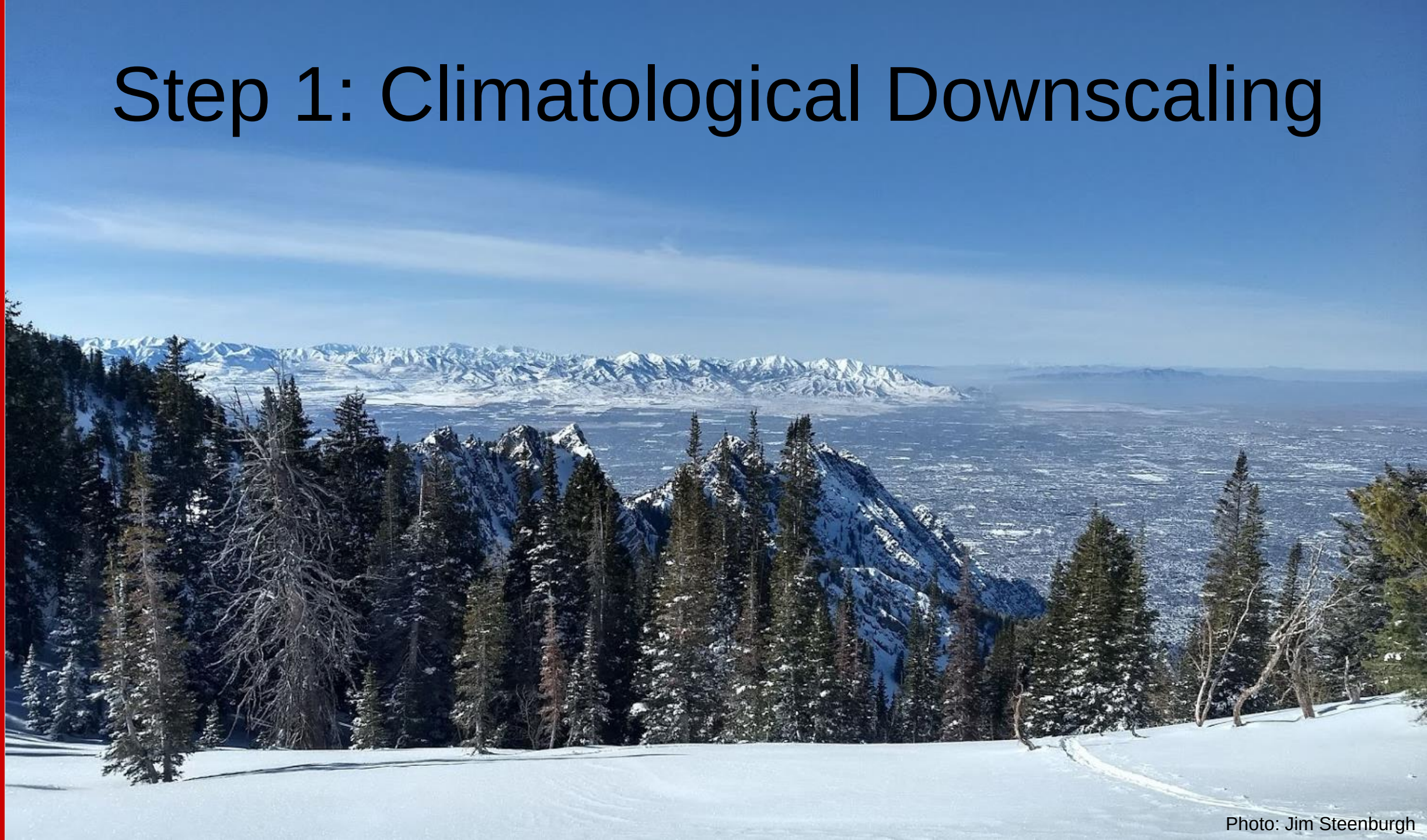
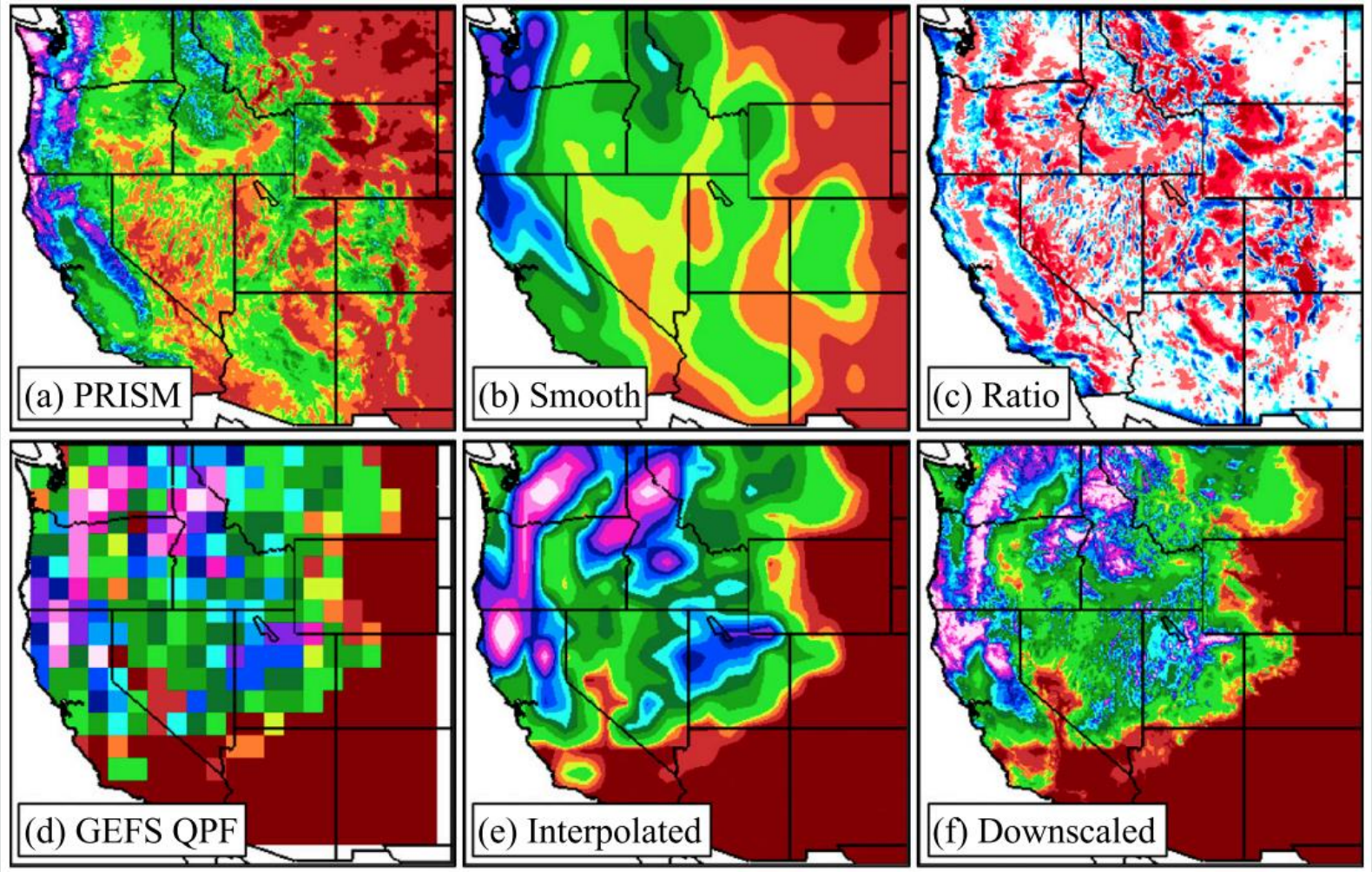


Photo: Jim Steenburgh

Step 1: Climatological Downscaling



Lewis et al. (2017)

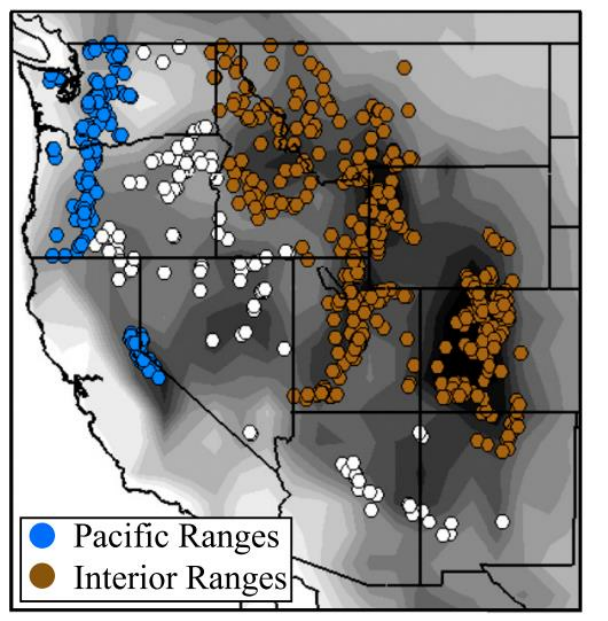
Advantages

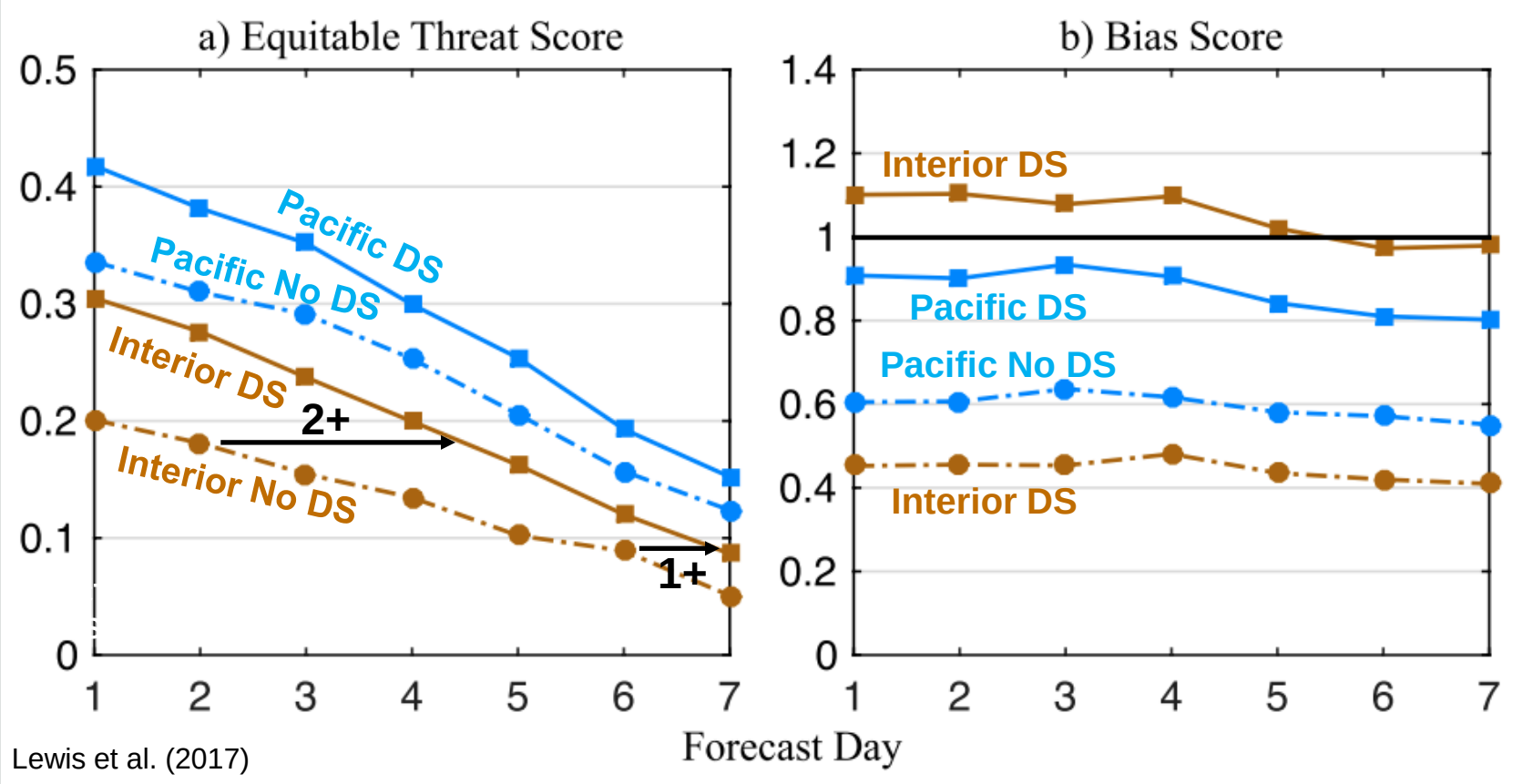
Requires no training
Works with any model
Fast
Looks realistic

Disadvantages

No model bias adjustment (this could be added)
No variations in orographic gradients

Step 1: Climatological Downscaling





Lewis et al. (2017)

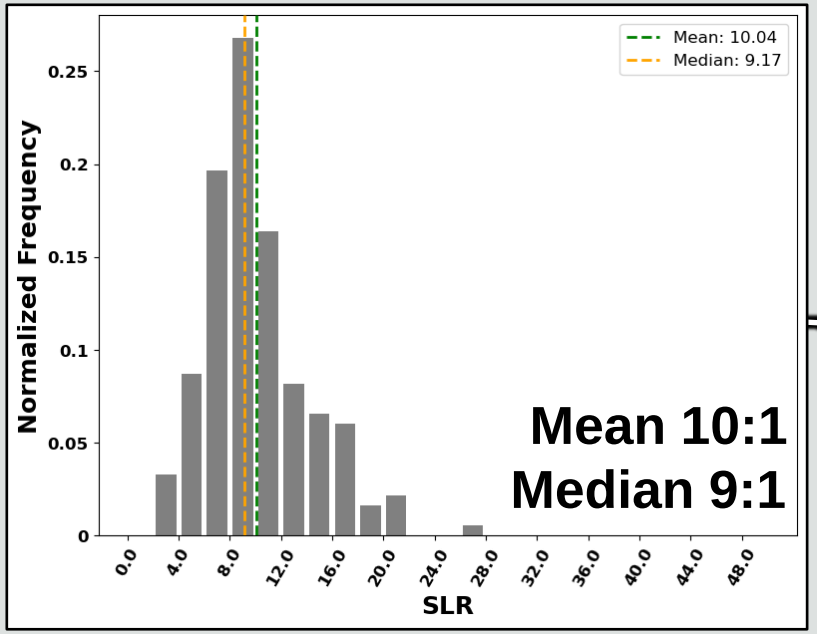
Upper-quartile events at SNOTEL stations
GEFS CTL with and without downscaling

TBD: How does this compare with quantile mapping or deep-learning approaches?

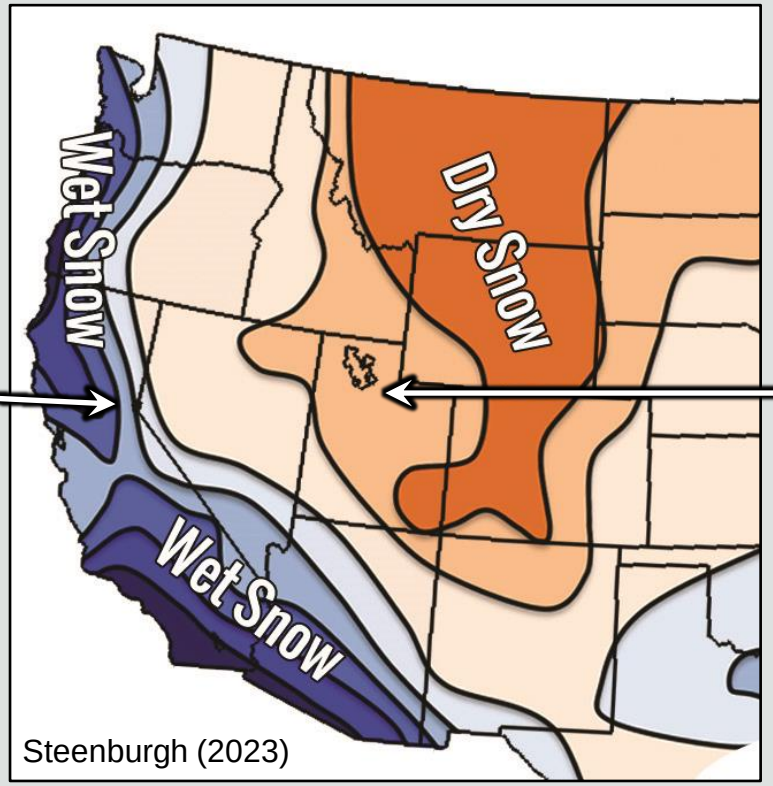
Step 2: Snow-to-Liquid Ratio (SLR)

Photo: Jim Steenburgh

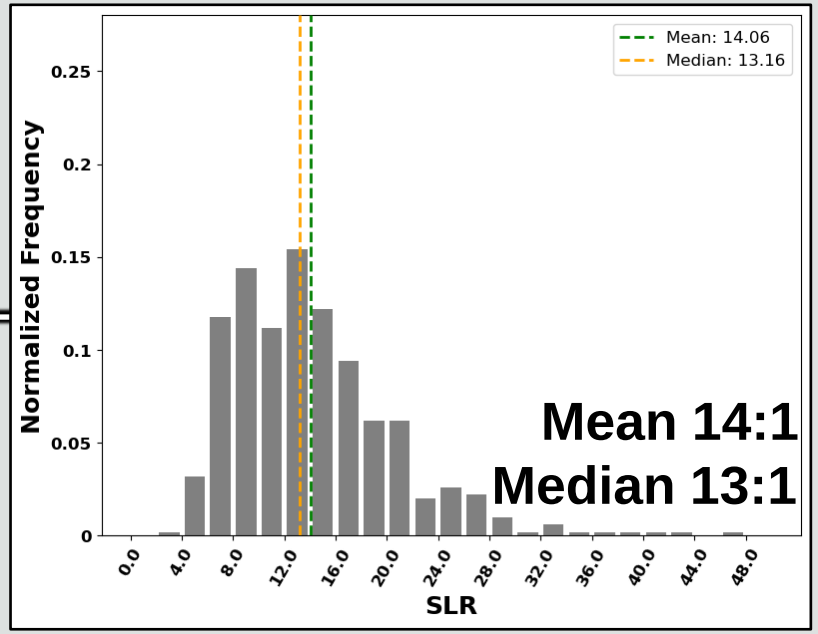
Snow-to-Liquid Ratio (SLR)



Central Sierra Snow Lab, CA



Mean

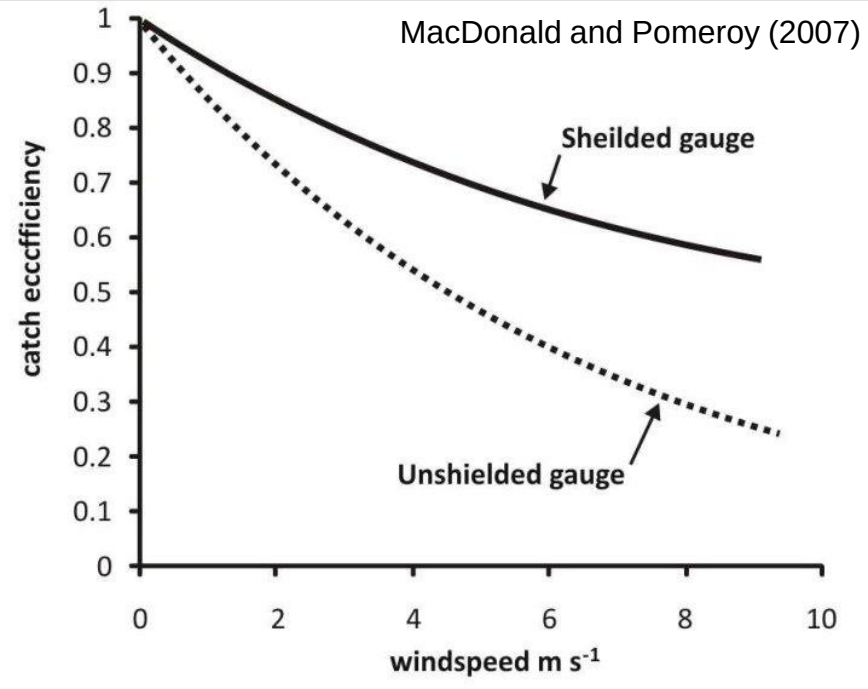


Alta, UT

On average, decreases from coast to interior, but exhibits large spatiotemporal variability

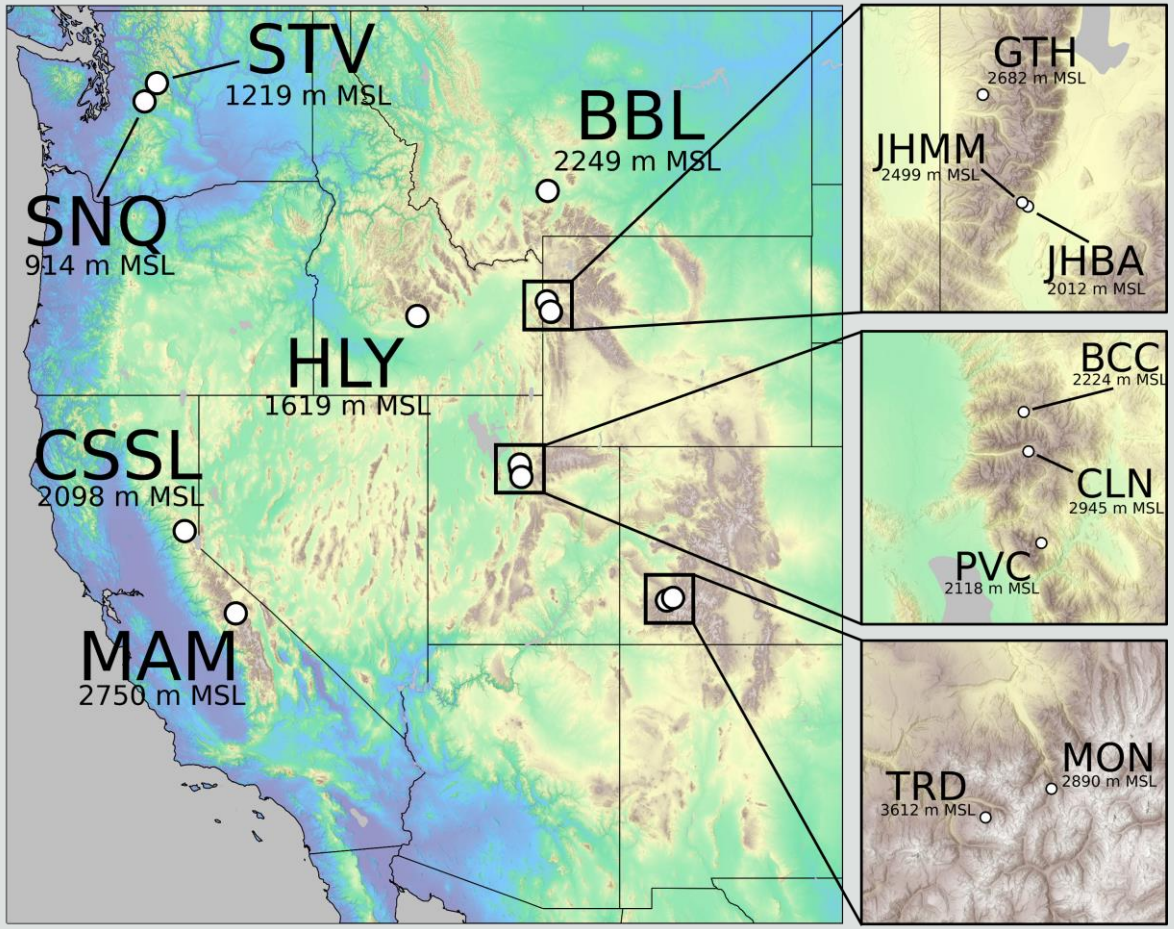
Our Approach

Focus on training and testing with high-quality observations (i.e., manual obs from snow-safety teams and other trained observers)



Gauge undercatch issues

Western CONUS Sites

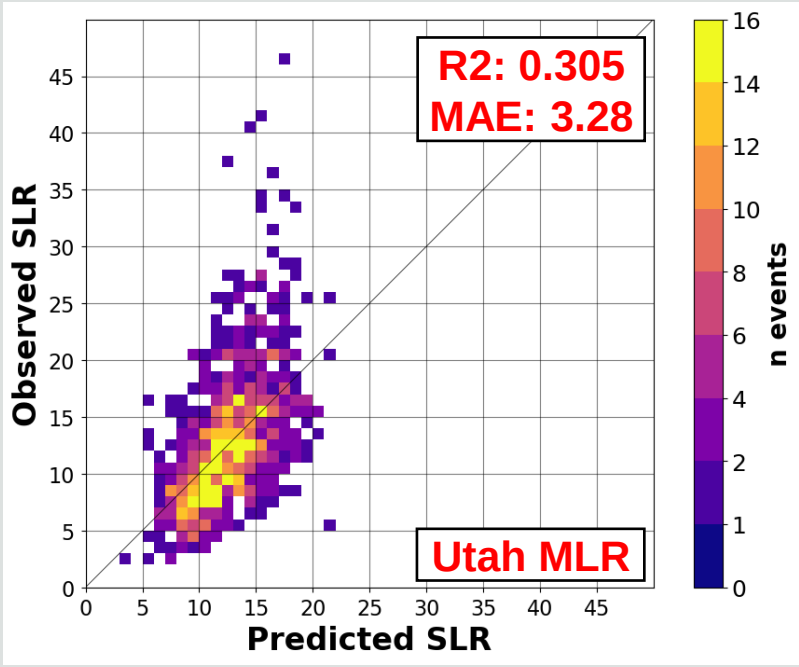


Data from 14 sites Nov–Apr 2018–2024 (CSSL, STV, and HLY 1-2 seasons less)

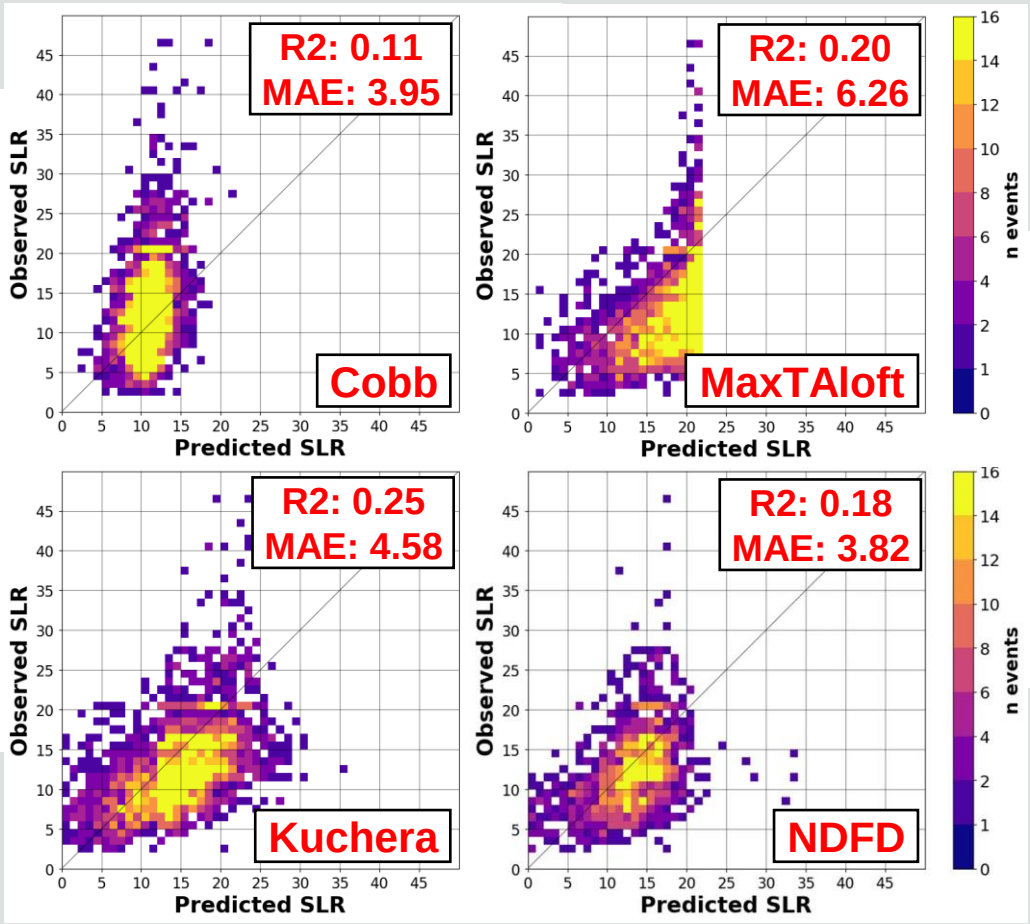
Events: > 5 cm snow; > 2.8 mm water

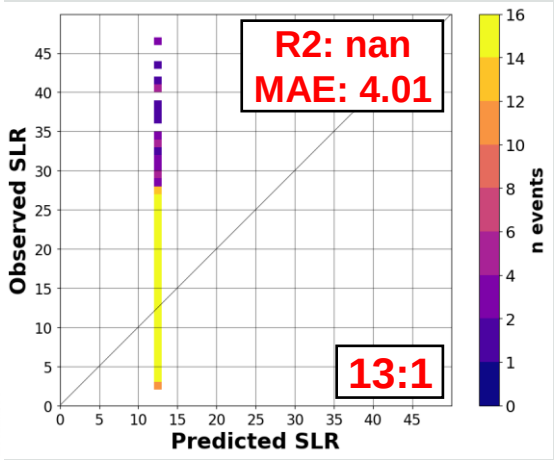
Toss 10:1 (placeholder)

Algorithm for GEFS/ENS



ERA5 Trained MLR with T, SPD At 500, 1000, 2000 m AGL



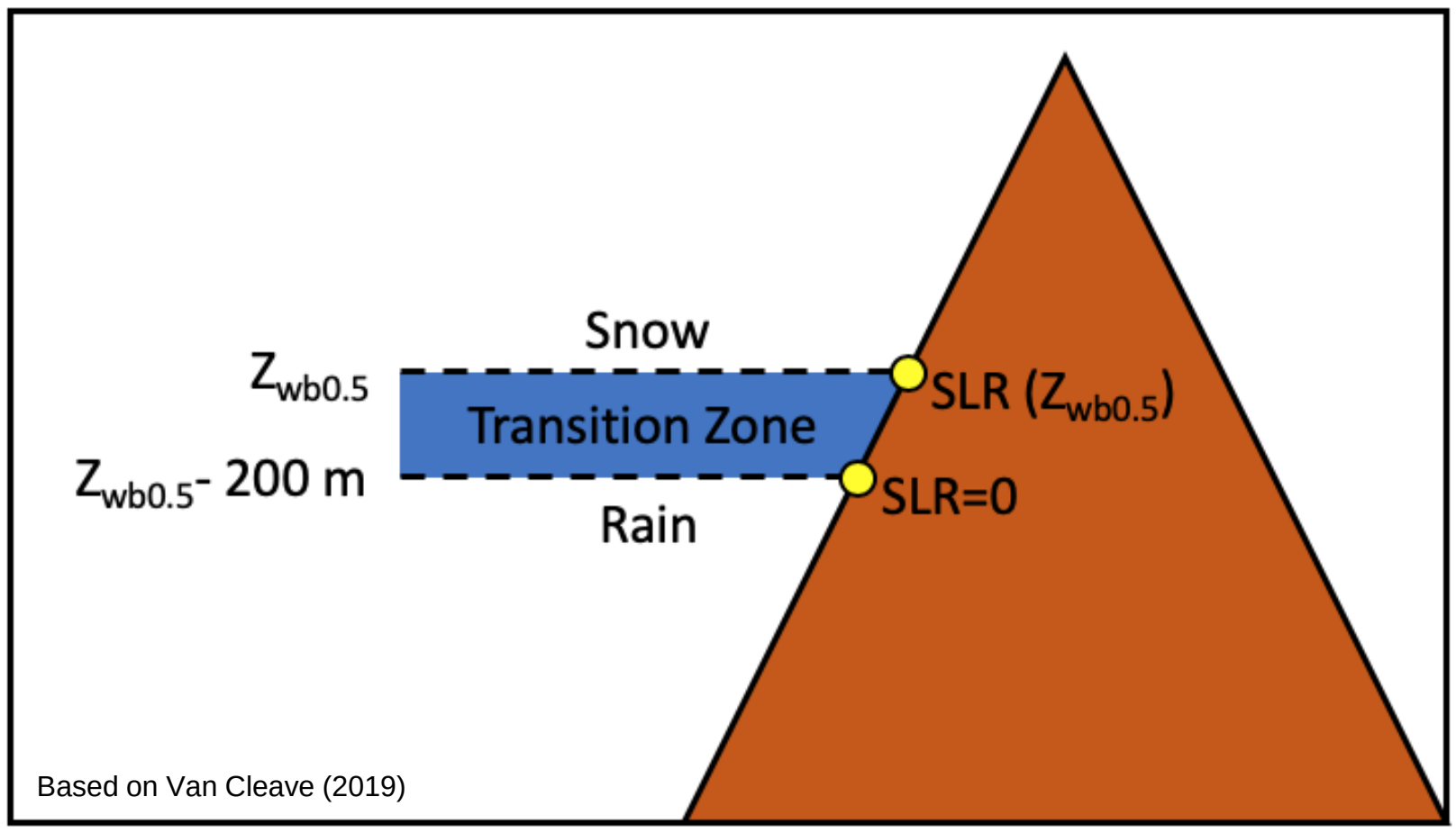


Random Forest with more levels and variables even better but computational cost higher

Step 3: Snow Level

Photo: https://pixabay.com/photos/lake-snow-line-mountains-forest-4733473/

Simple Is as Simple Does

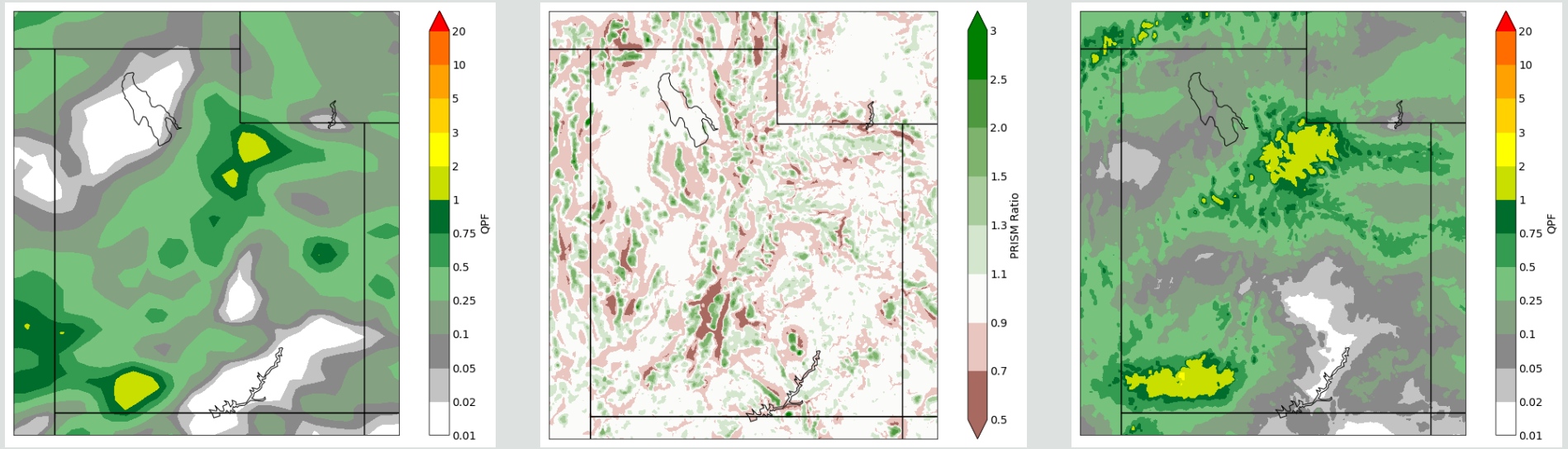


Currently not dealing with warm noses/mixed precipitation (issue in some PacNW areas)
Currently not dealing with on-the-ground melt and settlement in near 0ºC environments
Given low vertical res of available GEFS/ENS grids, will probably need ML approach

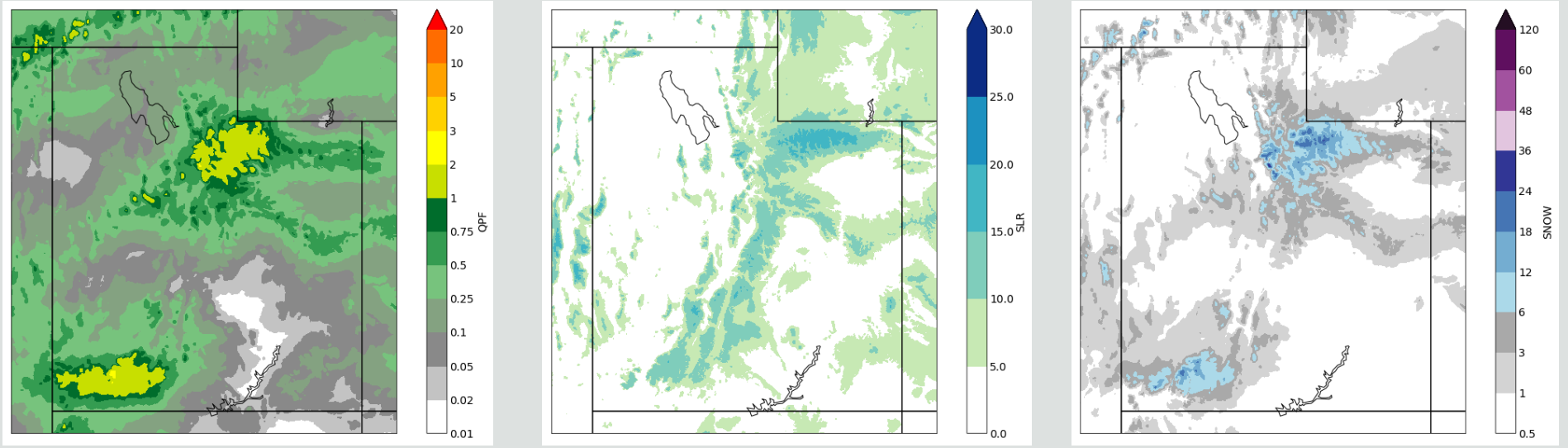
Putting It All Together

Photo: Jim Steenburgh

Model QPF X PRISM Ratios = Downscaled 800 m QPF



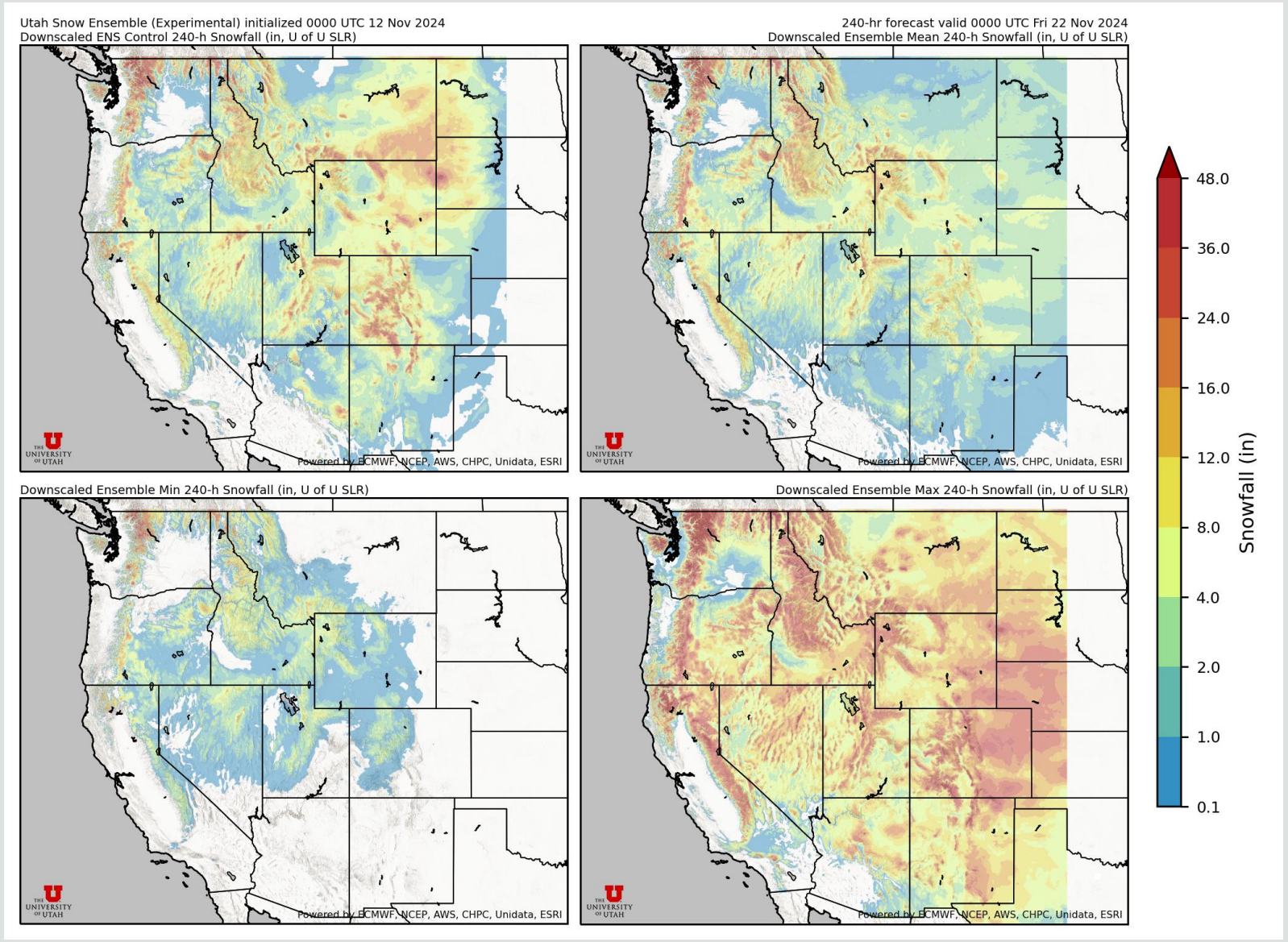
Downscaled 800 m QPF X Downscaled MLR SLR = Downscaled 800-m Snow



Utah Snow Ensemble = 31 GEFS Members + 51 ECMWF ENS members every 6h to 240 h = 3280 members:fhrs

Utah Snow Ensemble

CTL 240-h Snowfall



Mean 240-h Snowfall

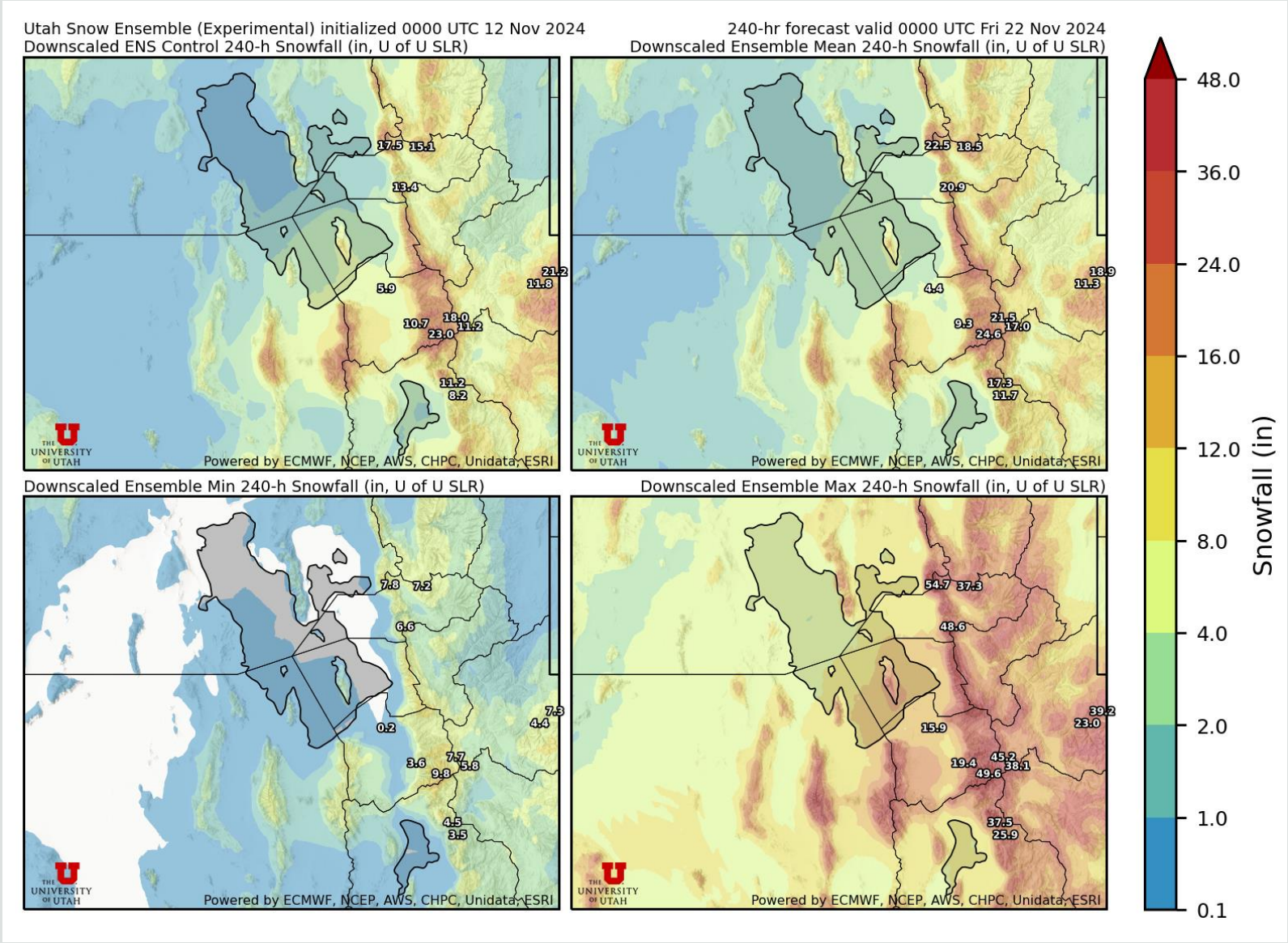
Min 240-h Snowfall

Max 240-h Snowfall

Utah Snow Ensemble

CTL 240-h Snowfall

Min 240-h Snowfall



Mean 240-h Snowfall

Max 240-h Snowfall

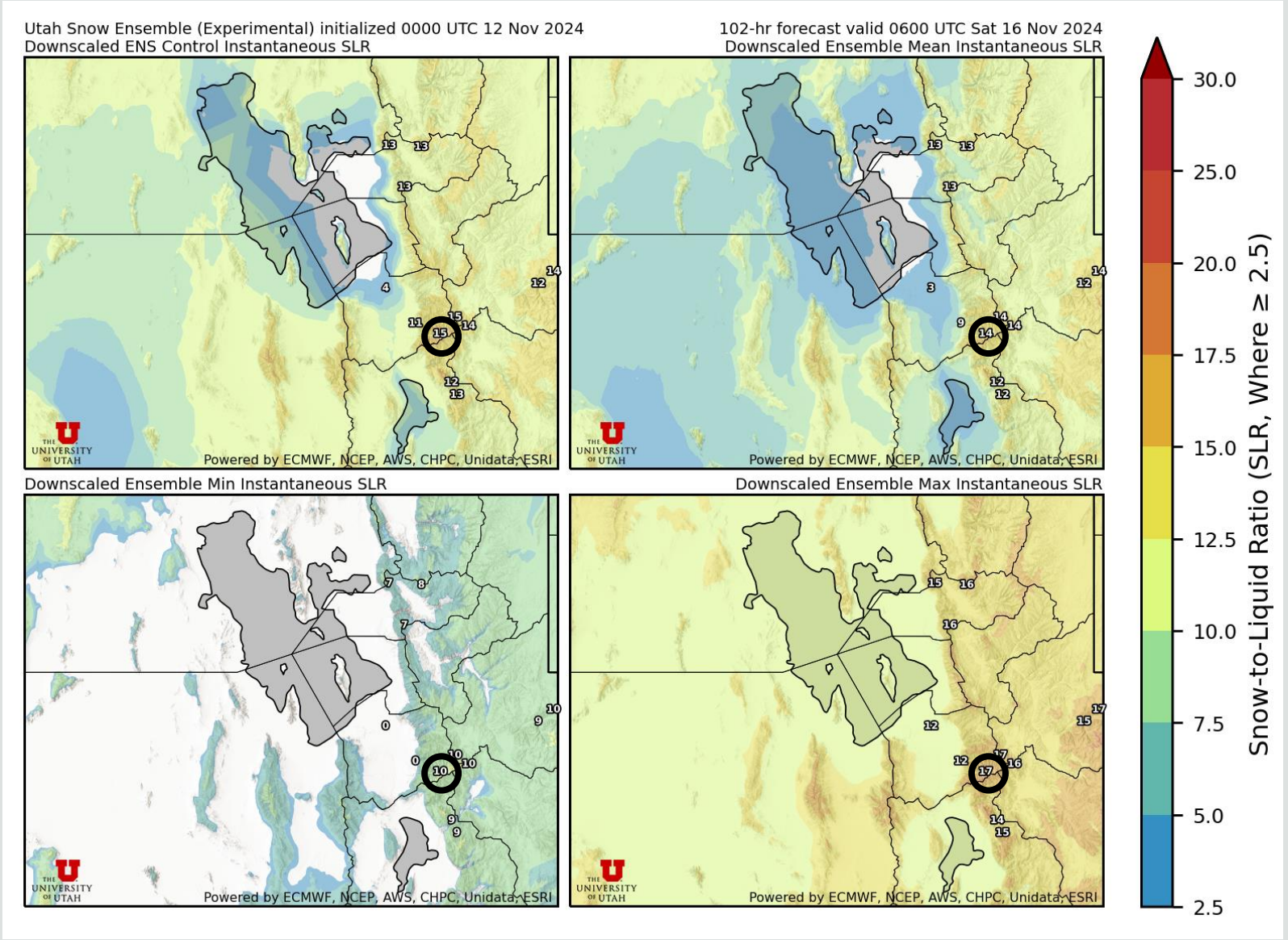
Utah Snow Ensemble

CTL 102-h SLR

Mean 102-h SLR

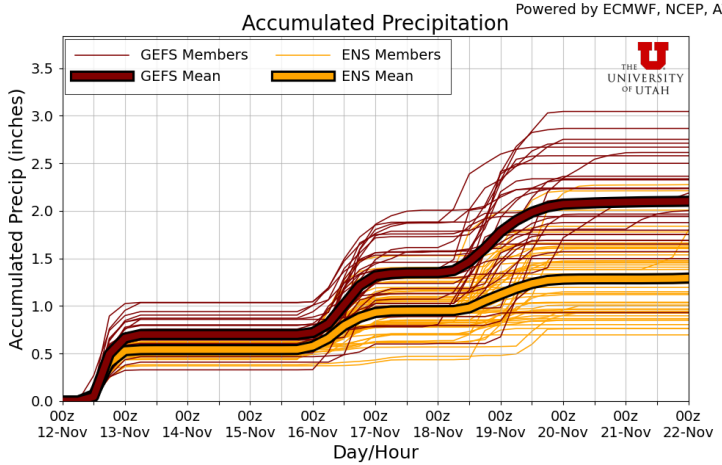
Min 102-h SLR

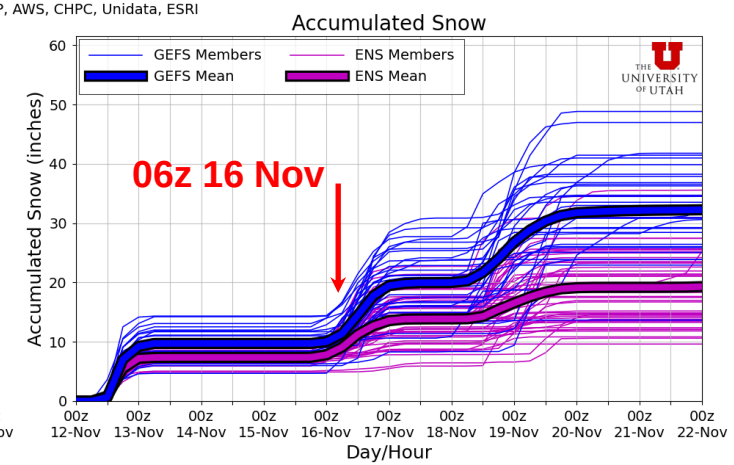
Max 102-h SLR



Utah Snow Ensemble (Experimental) Initialized 0000 UTC 12 Nov 2024 (82 Members)
Guidance for 40.579N -111.654W 9416 ft AMSL [Nearest Grid Point to Alta-Collins, UT (CLN)]
Powered by ECMWF, NCEP, AWS, CHPC, Unidata, ESRI

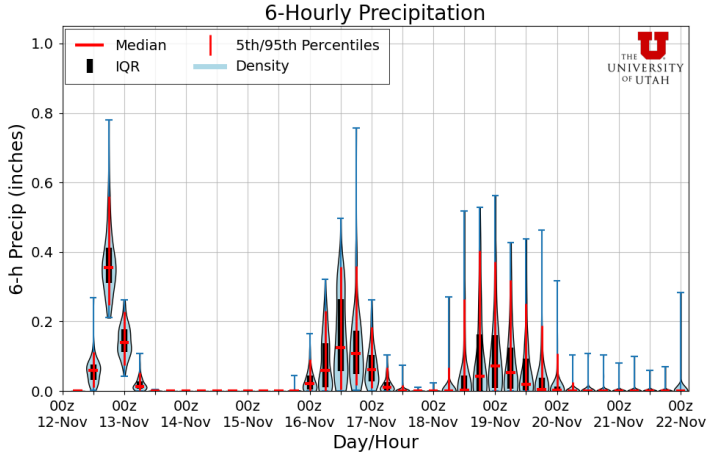
Accumulated Precip

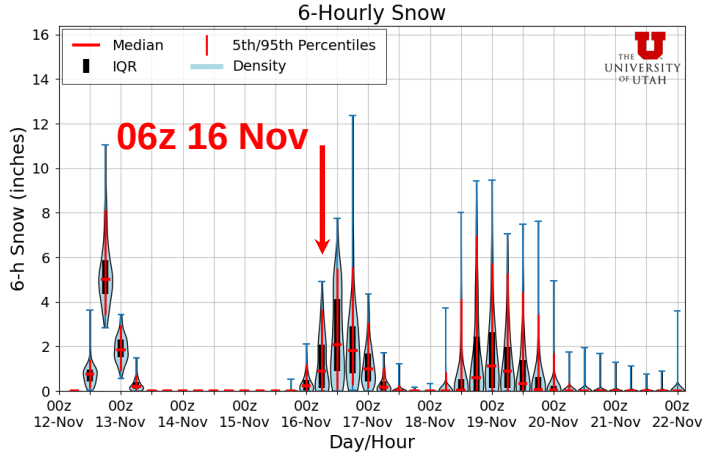




Accumulated Snow

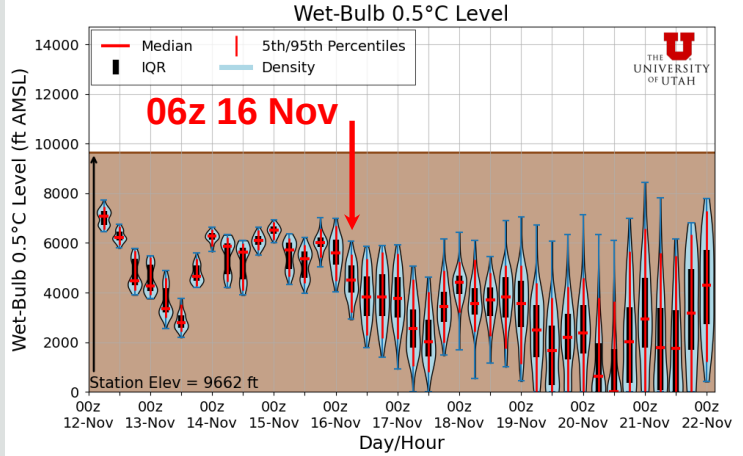
6-h Precip

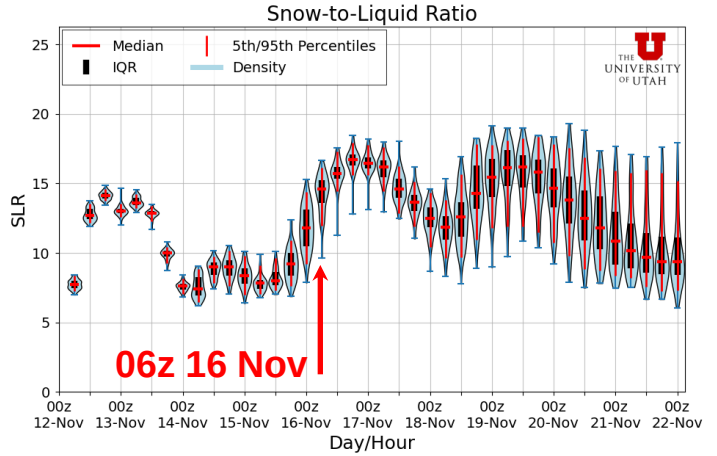




6-h Snow

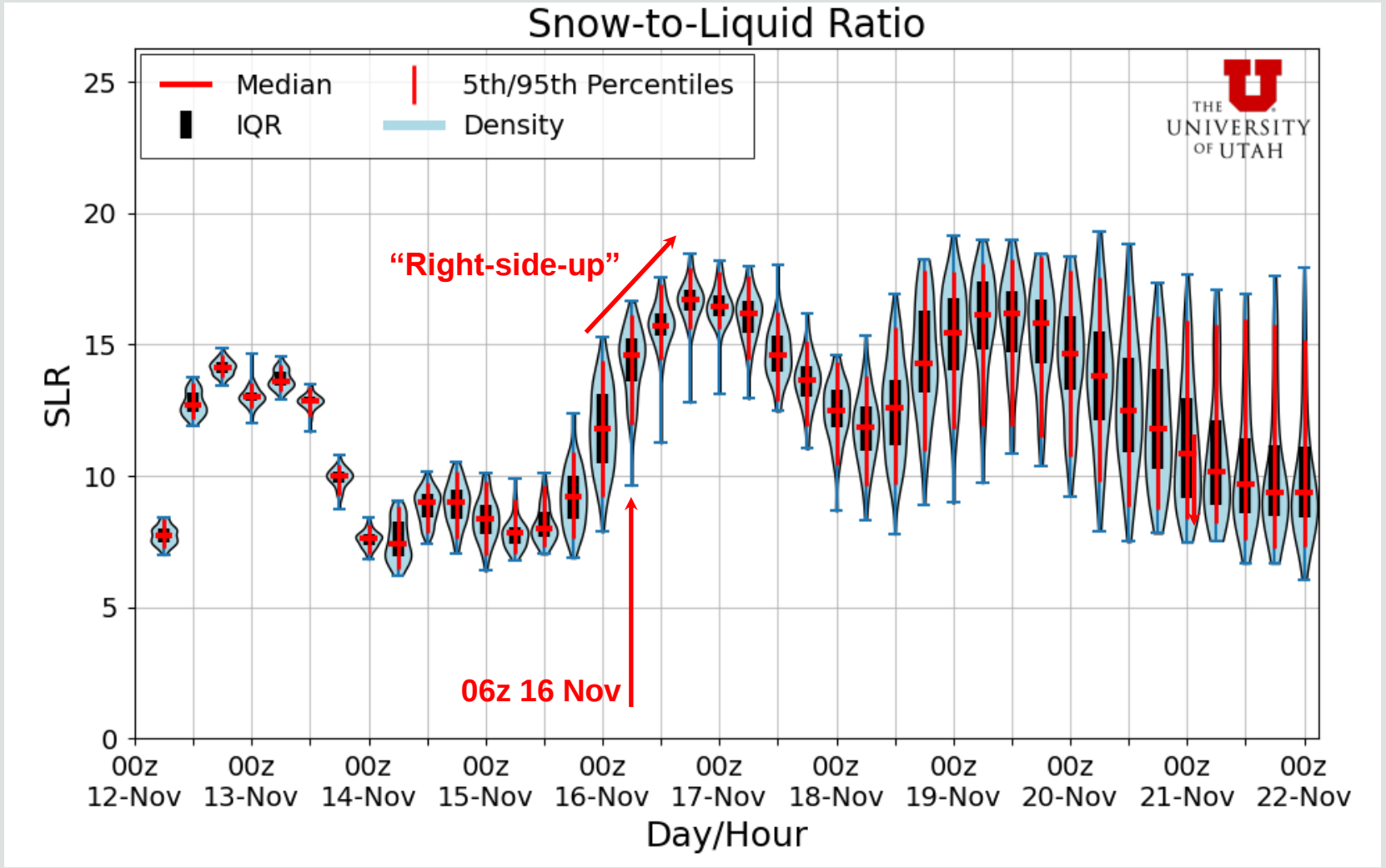
Probabilistic 0.5°C Level

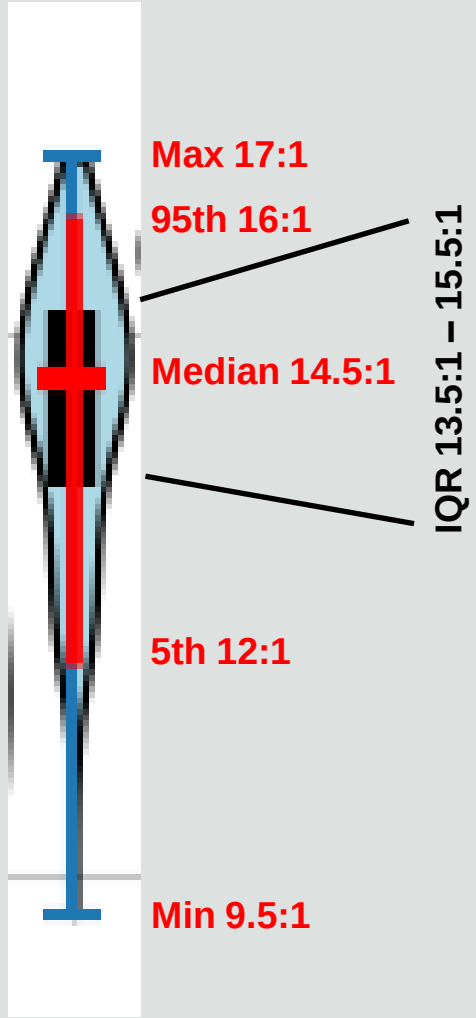




Probabilistic SLR

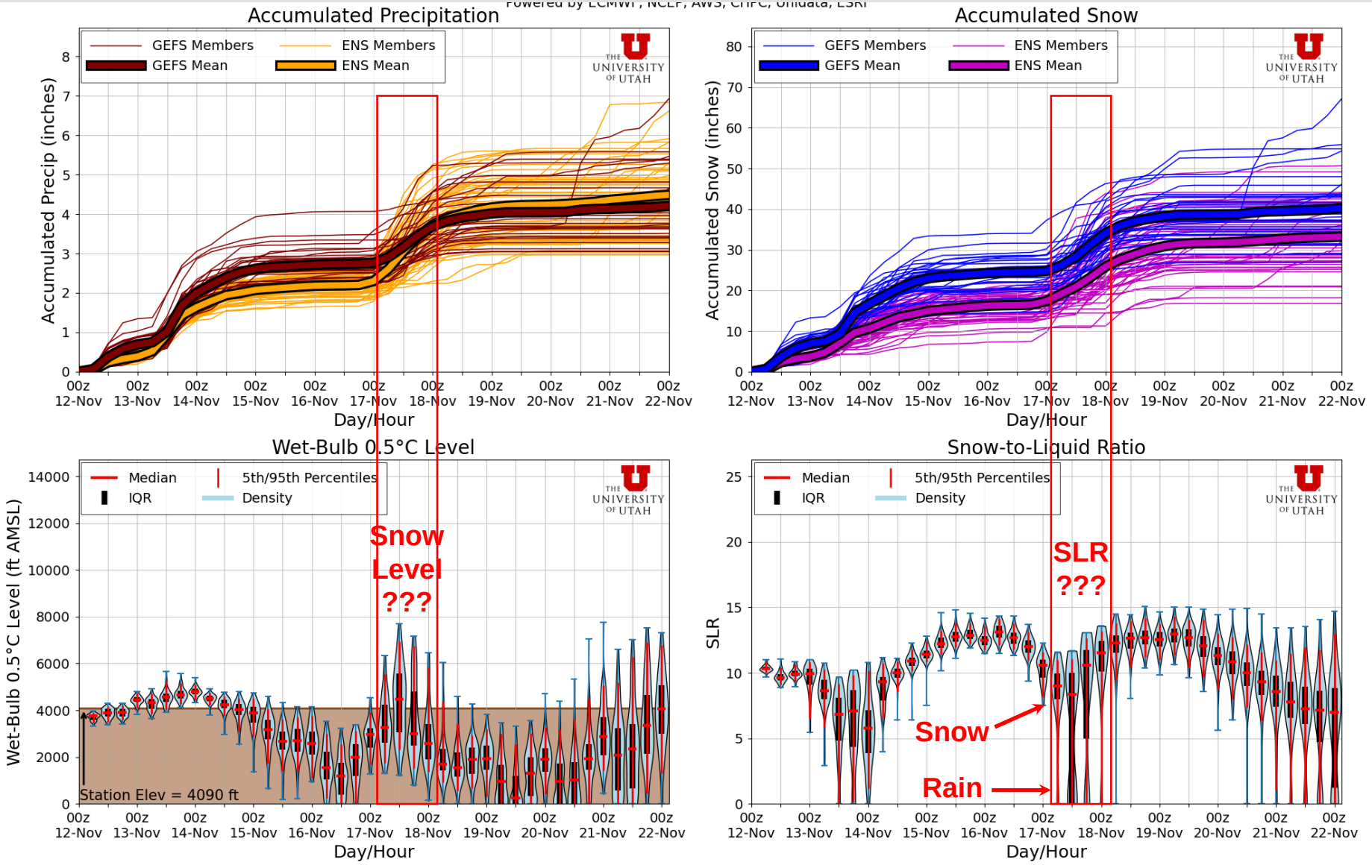
SLR Probabilities





06z 16 Nov

Stevens Pass, WA



Feedback & Usage

“*Kudos to the team that developed [the Utah Snow Ensemble], as it’s been an extremely helpful tool for our forecasts*!”
– Forecaster, NWSFO Reno

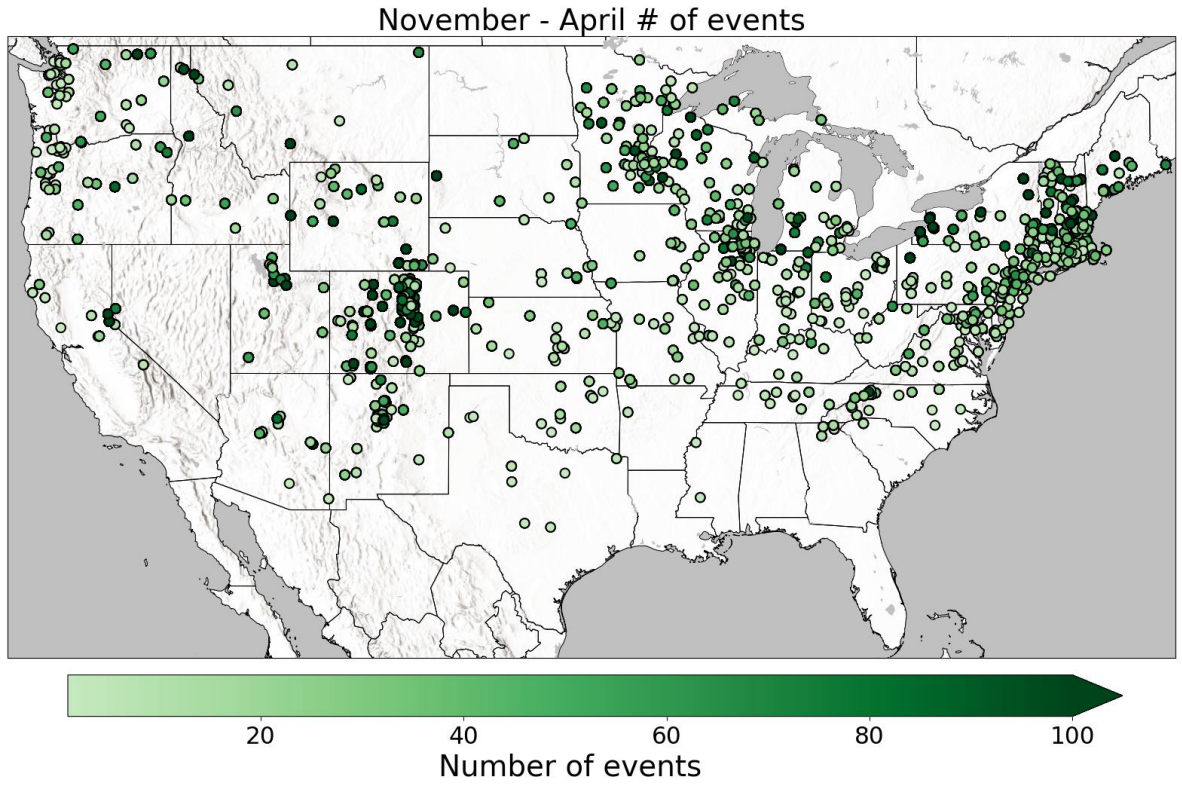
“*The success of our avalanche forecasting at UDOT has benefited tremendously from the research work completed…at the University of Utah. The winter precipitation research and visualization tools available at weather.utah.edu have become essential tools for our program.*”
– Steven Clark, UDOT Avalanche Safety Program Manager

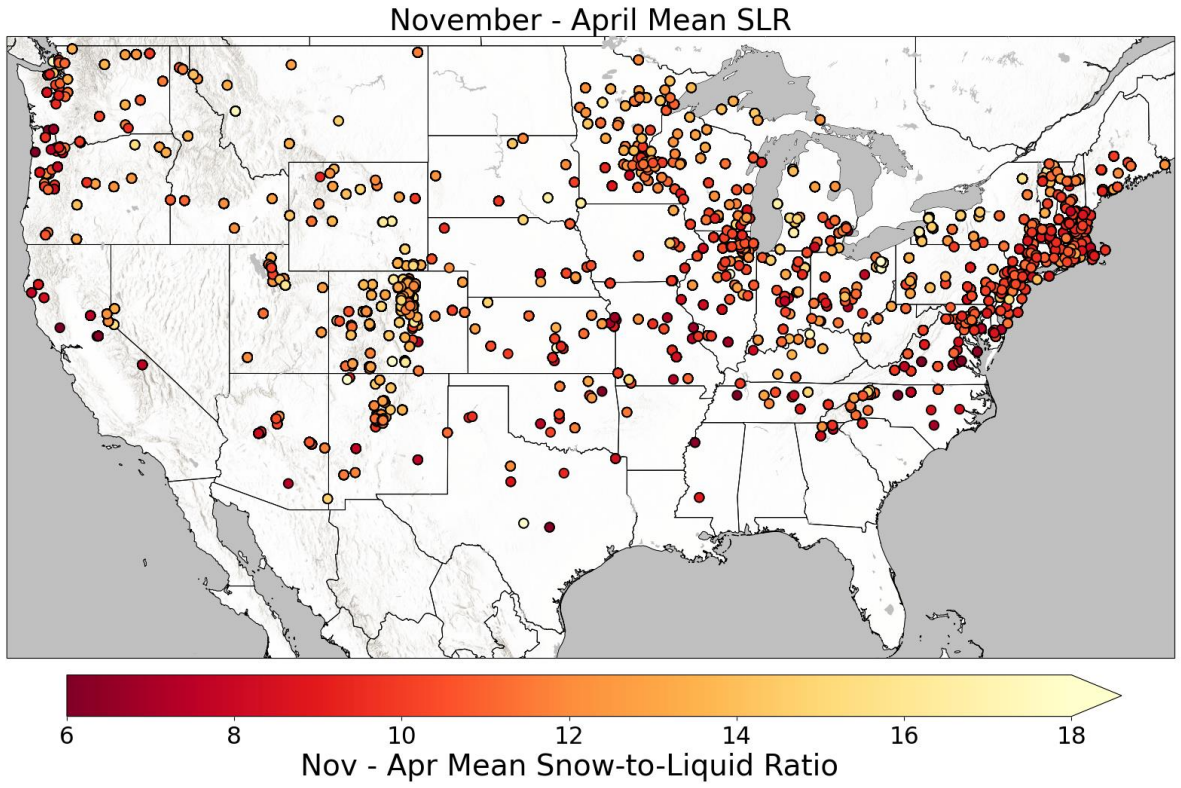
weather.utah.edu: 23 million hits in past year

Beyond the Western CONUS

Photo: Yohan Marion/Unsplash,https://www.washingtonian.com/2023/11/09/snow-lovers-rejoice-dc-weather-experts-are-forecasting-flakes-this-winter/

CoCoRaHS SLR Observations





Sites where observers manually measure snowfall
921 unique sites across CONUS; 24-h observing periods

Random Forest Development

- **Random forest (RF): Aggregates predictions from an ensemble of decision trees to make a deterministic prediction**
- **Trained with ERA5 Reanalysis and CoCoRAHS 24-h SLR obs; 60/40 train/validate split**
- **Training period: December 2000 to April 2022**
- **Testing period: November 2022 to April 2024 (testing performed on the HRRR)**

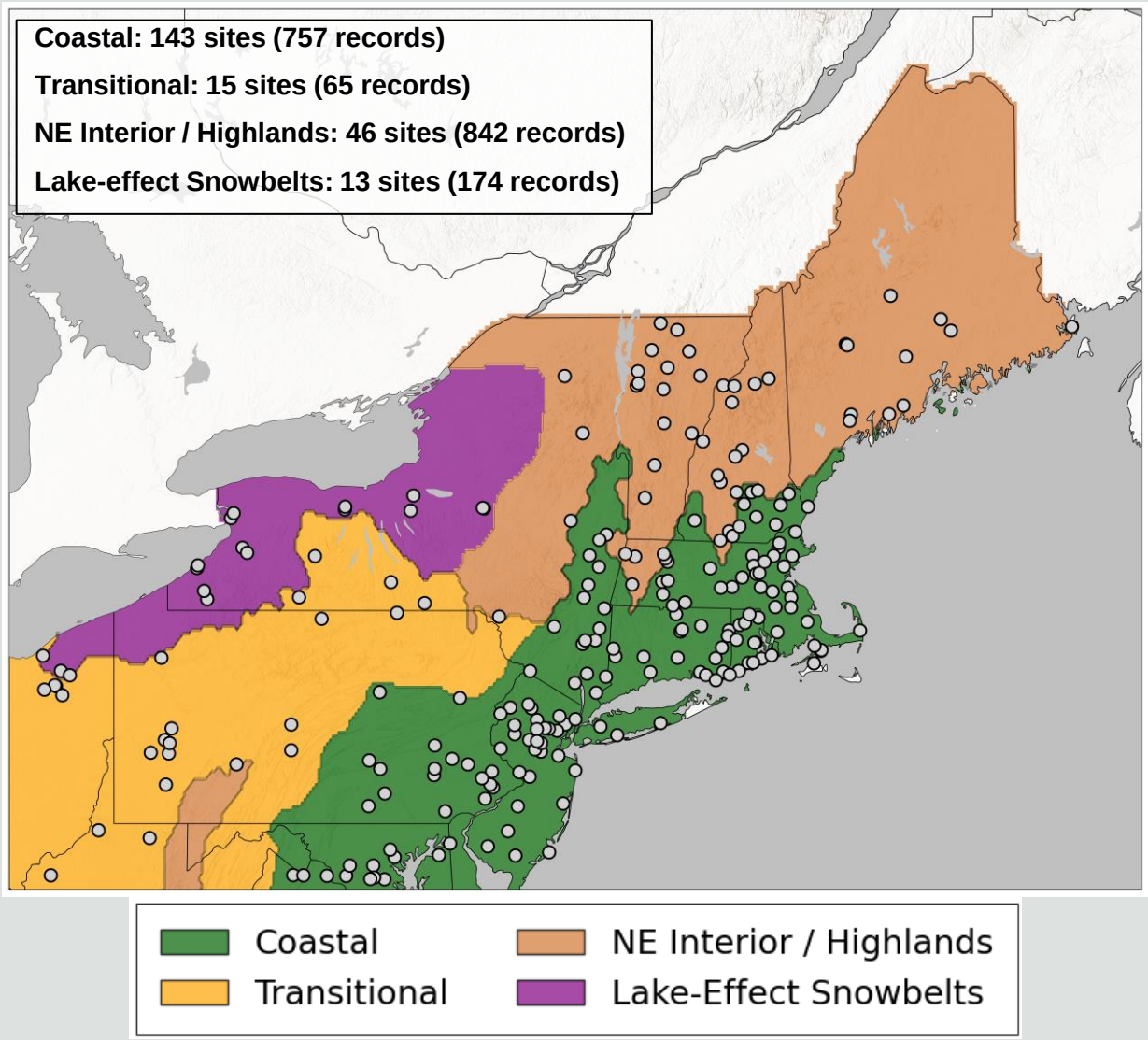
Input Features

Variable	Levels
Temperature	300, 600, 900, 1200, 1500, 1800, 2100, 2400 m above ground level
Wind speed	300, 600, 900, 1200, 1500, 1800, 2100, 2400 m above ground level
Relative humidity	300, 600, 900, 1200, 1500, 1800, 2100, 2400 m above ground level
Latitude	N/A
Longitude	N/A
Elevation	N/A

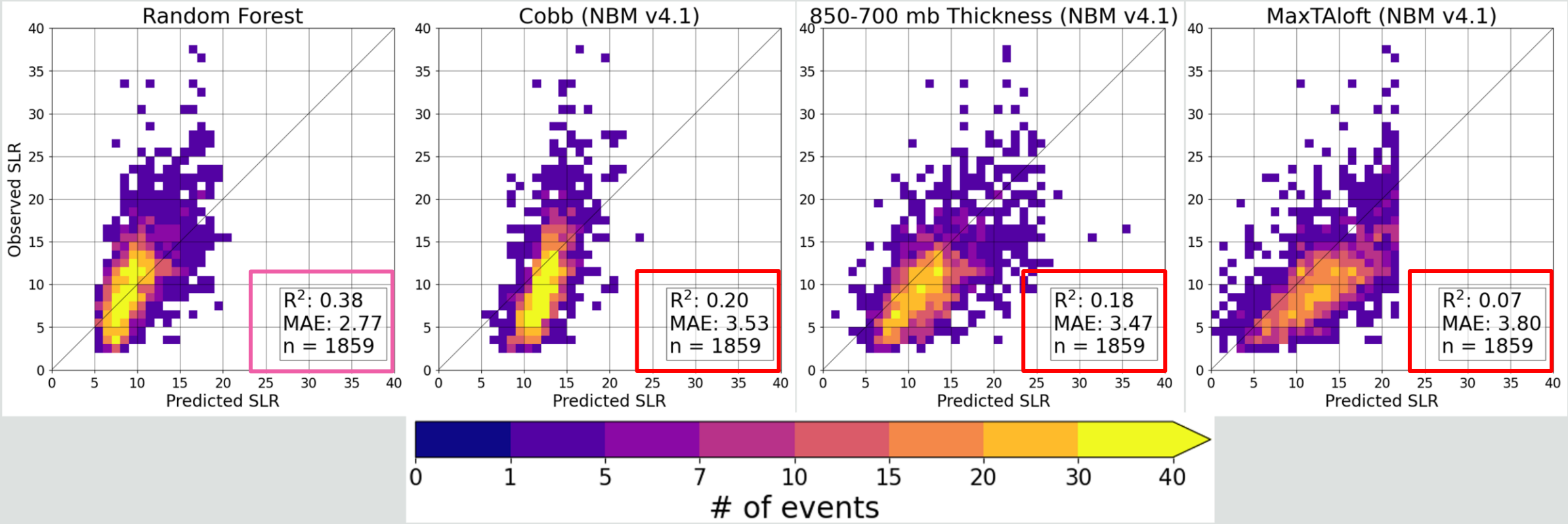
Most predictors were chosen based on results from previous studies [Roebber et al. (2003); Cobb and Waldstreicher (2005); Alcott and Steenburgh (2010)]

Northeast CONUS Snow Climates

- **Eight CONUS snow climates defined using**
  - **National Operational Hydrologic Remote Sensing Center (NOHRSC) Snow Analysis**
  - **Baxter et al. (2005) SLR Climatology**
- **Test SLR method performance within each snow climate**



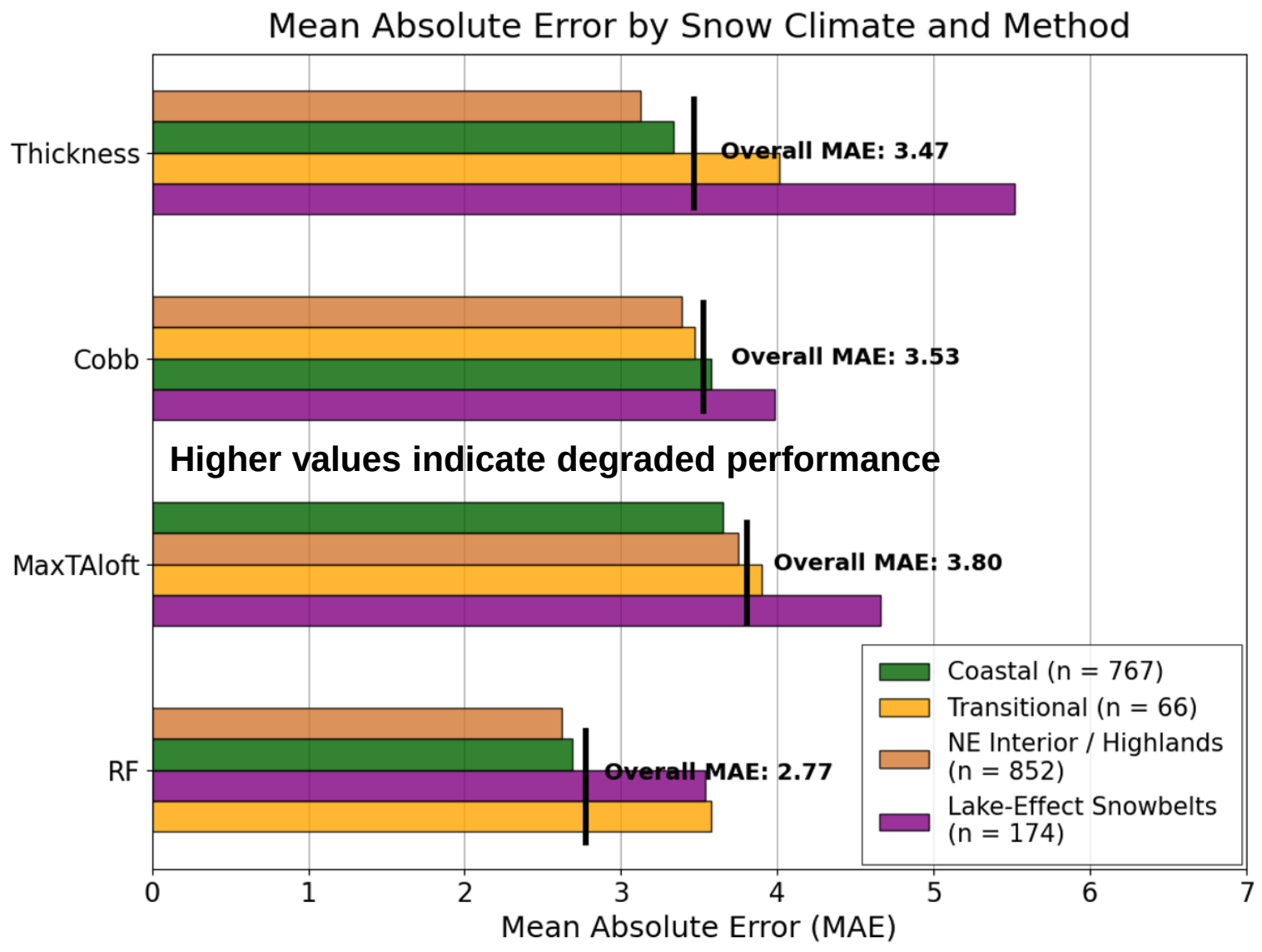
NE CONUS Performance



ERA5, CONUS-wide trained RF applied to HRRR Nov 2022 – Apr 2024 cool seasons
RF performs best across the northeast CONUS

RF is only method that beats 10:1, 13:1, and Site SLR Climo (not shown)

NE CONUS Performance



- **RF exhibits lowest MAE for all snow climates; MaxTAloft highest**
- **All methods are least accurate for lake-effect events (more SLR variability)**

Summary

- We have the datasets and code to develop ML models for SLR that can be applied to operational forecast models
- Combined with statistical downscaling, we are producing high-res forecasts of SLR & snowfall from the GEFS & ECWMF ENS over the western CONUS
- We are also producing CONUS-wide SLR & snowfall forecasts from the RRFS ensemble
- We are working with WPC and EMC to evaluate & transfer into operations
- Interested in forging additional collaborations
- See http://weather.utah.edu for forecasts