# Predicting Snow-to-Liquid Ratio Across the CONUS

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**NOAA/ESRL**

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**WPC**

**Randy Chase, CoCoRAHS Team**
**Colorado State University**

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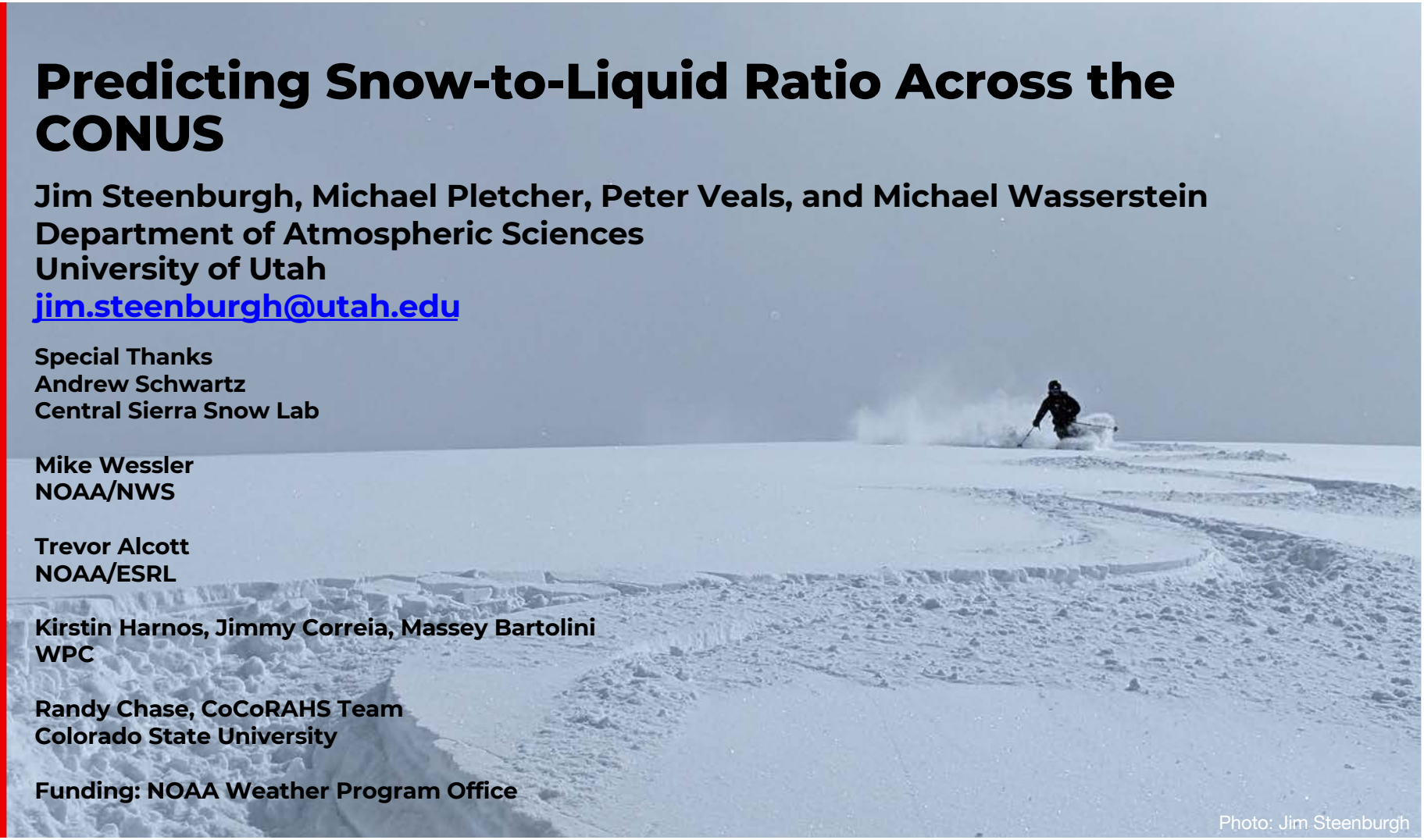


Photo: Jim Steenburgh

# Predicting Snow-to-Liquid Ratio Across the CONUS

1. Utah Snow Ensemble (Western CONUS)
2. What We Built for the RRFS (CONUS-wide)

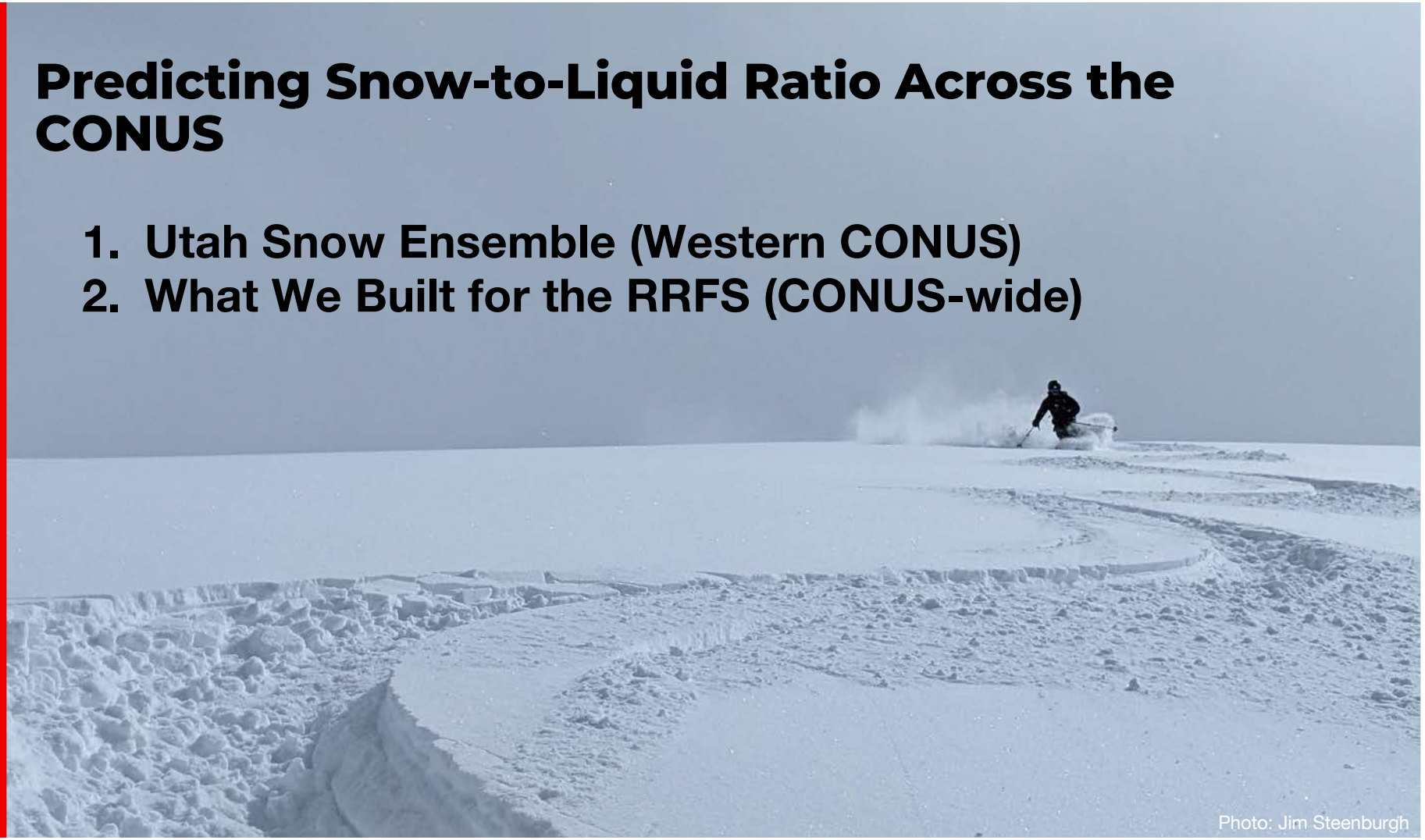
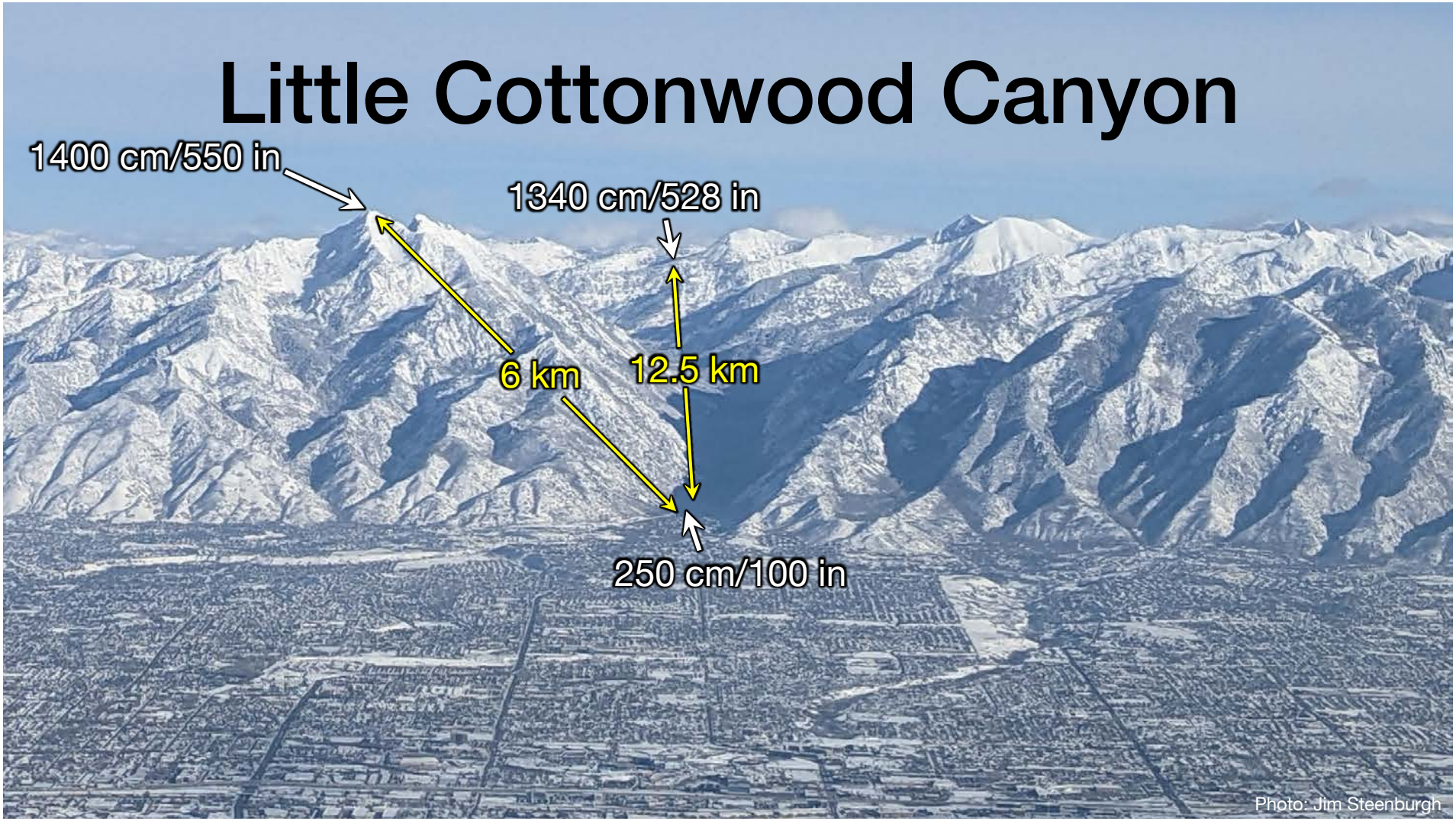


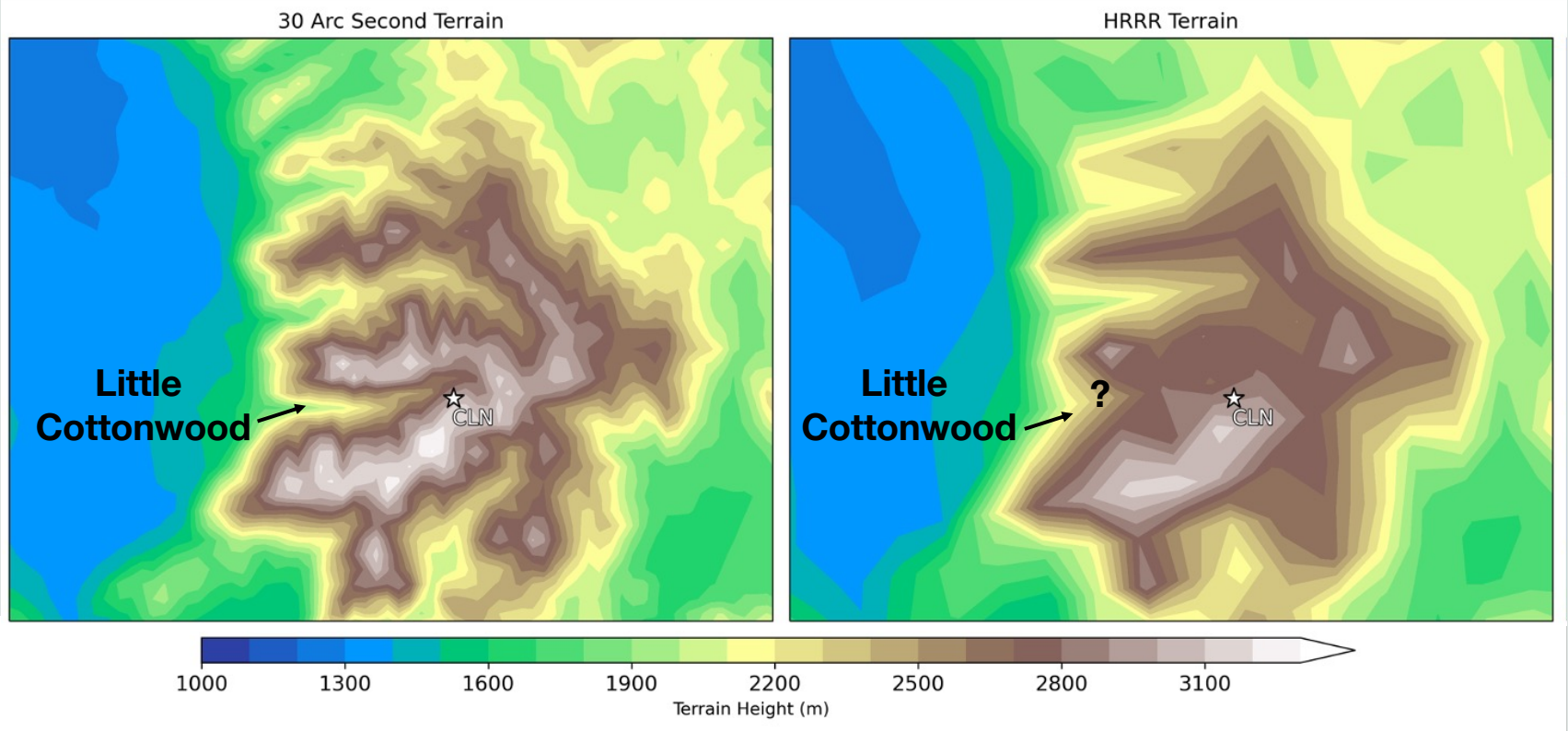
Photo: Jim Steenburgh

# Utah Snow Ensemble: 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

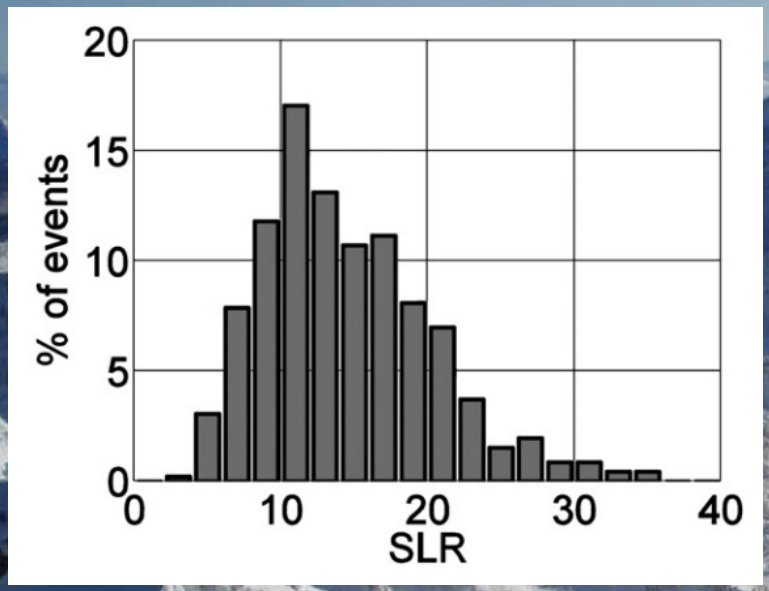

Little Cottonwood Canyon
1400 cm/550 in
1340 cm/528 in
6 km
12.5 km
250 cm/100 in
Photo: Jim Steenburgh

# HRRR Terrain Representation




Courtesy Michael Wasserstein, University of Utah

# 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

# Step 1: Climatological Downscaling

Photo: Jim Steenburgh

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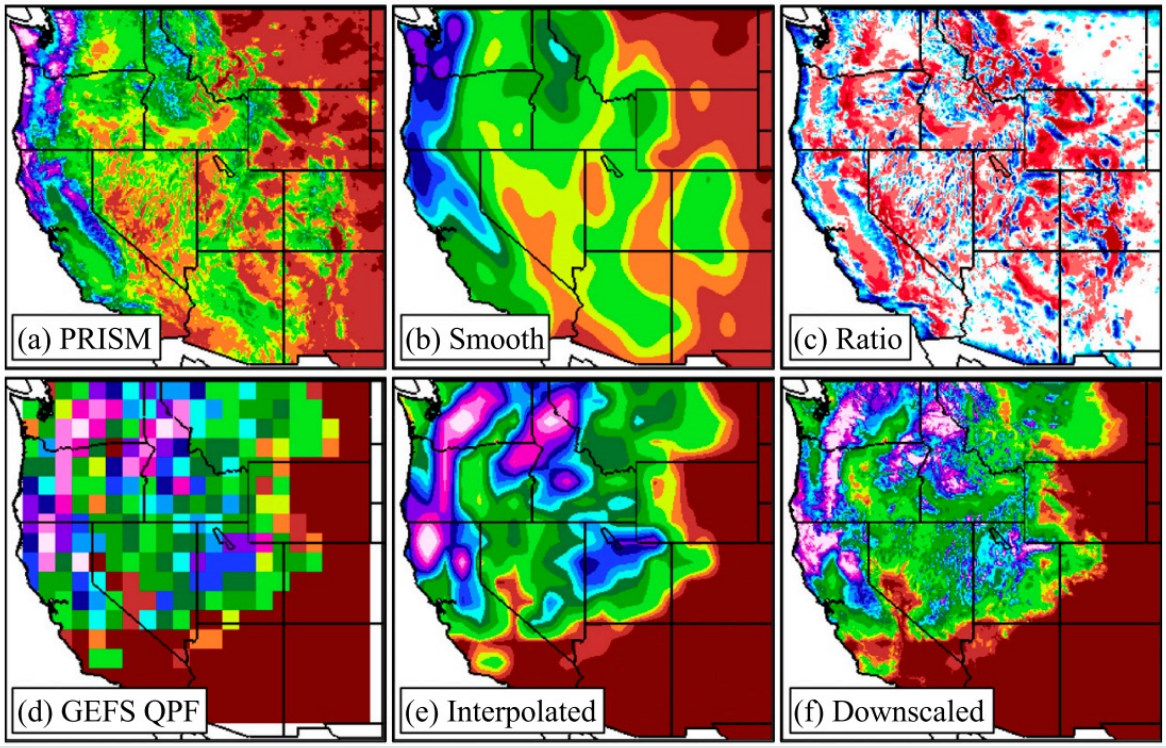



Lewis et al. (2017)

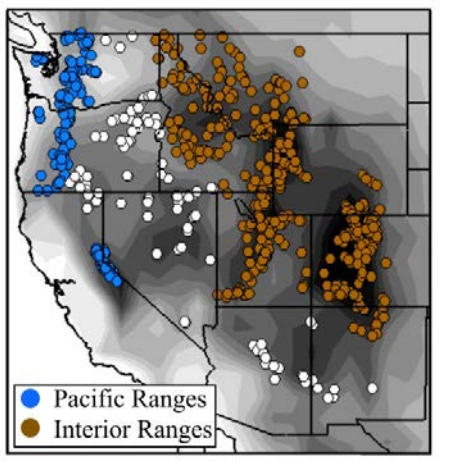
**Advantages**

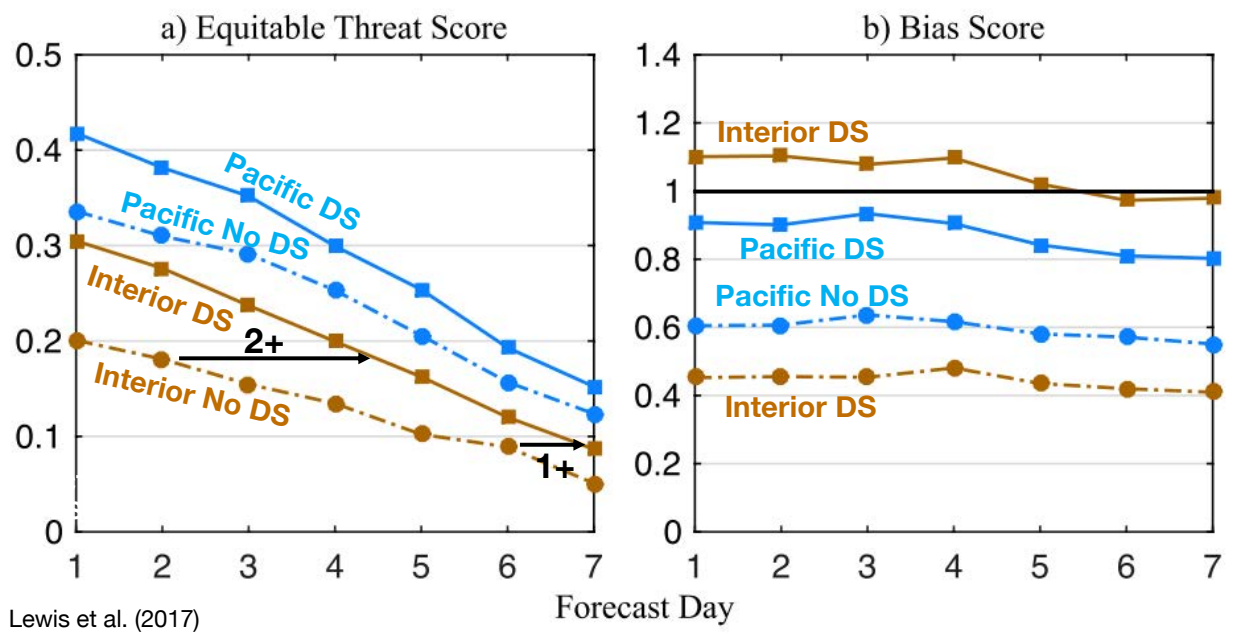
**Requires no training**
**Works with any model**
**Fast**
**Looks realistic**

**Disadvantages**

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

# Step 1: Climatological Downscaling




Lewis et al. (2017)

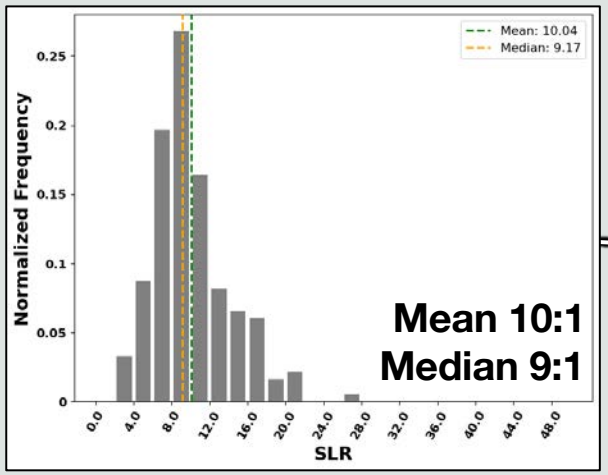
**Upper-quartile events at SNOTEL stations**
**GEFS CTL with and without downscaling**

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

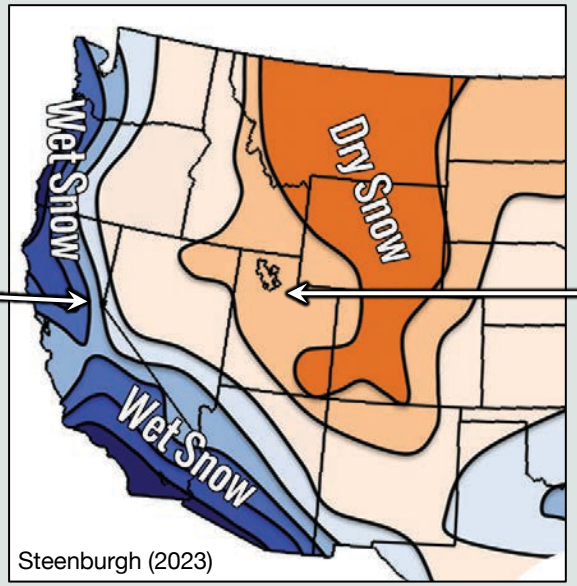
# Step 2: Snow-to-Liquid Ratio (SLR)

Photo: Jim Steenburgh

# Snow-to-Liquid Ratio (SLR)

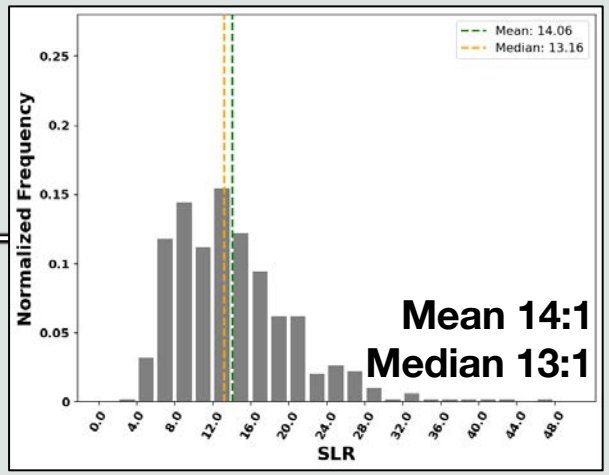



Central Sierra Snow Lab, CA




Steenburgh (2023)

Mean

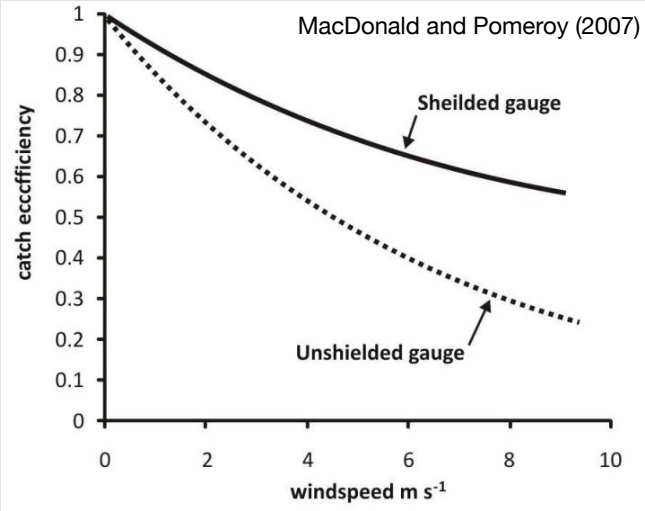



Alta, UT

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

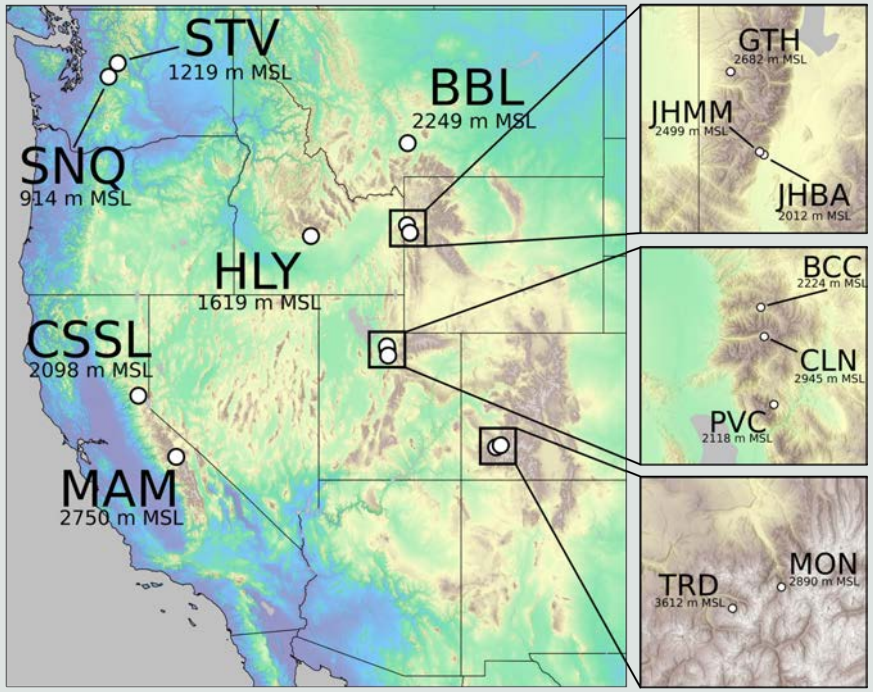
# Our Approach

**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

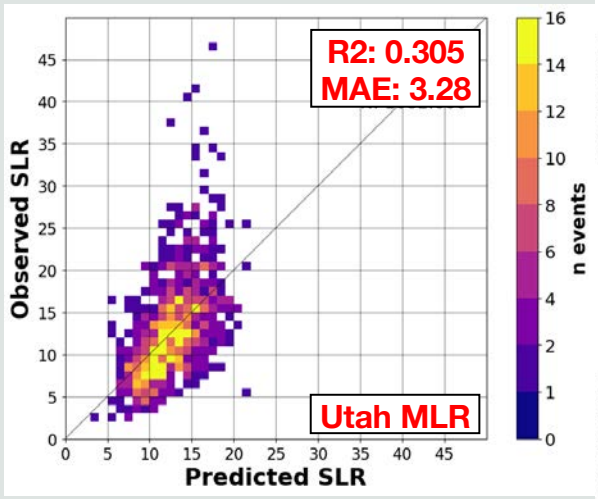



**Data from 14 sites Nov–Apr 2018–2024 (CSSL, STV, and HLY 1-2 seasons less)**

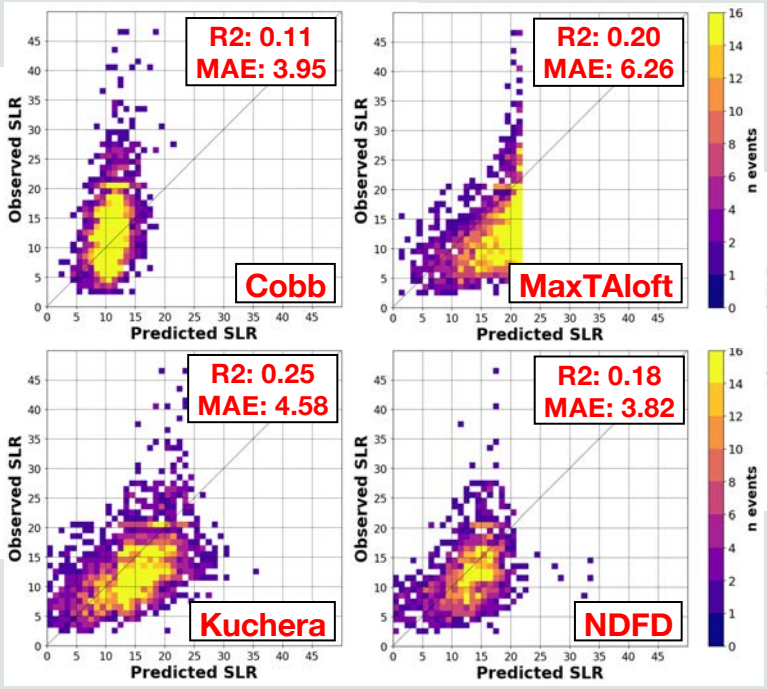
**Events: > 5 cm snow; > 2.8 mm water**

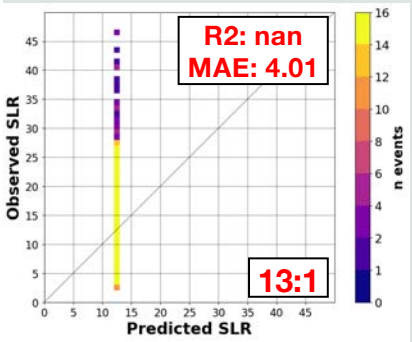
**Toss 10:1 (placeholder)**

# Algorithm for GEFS/ENS




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



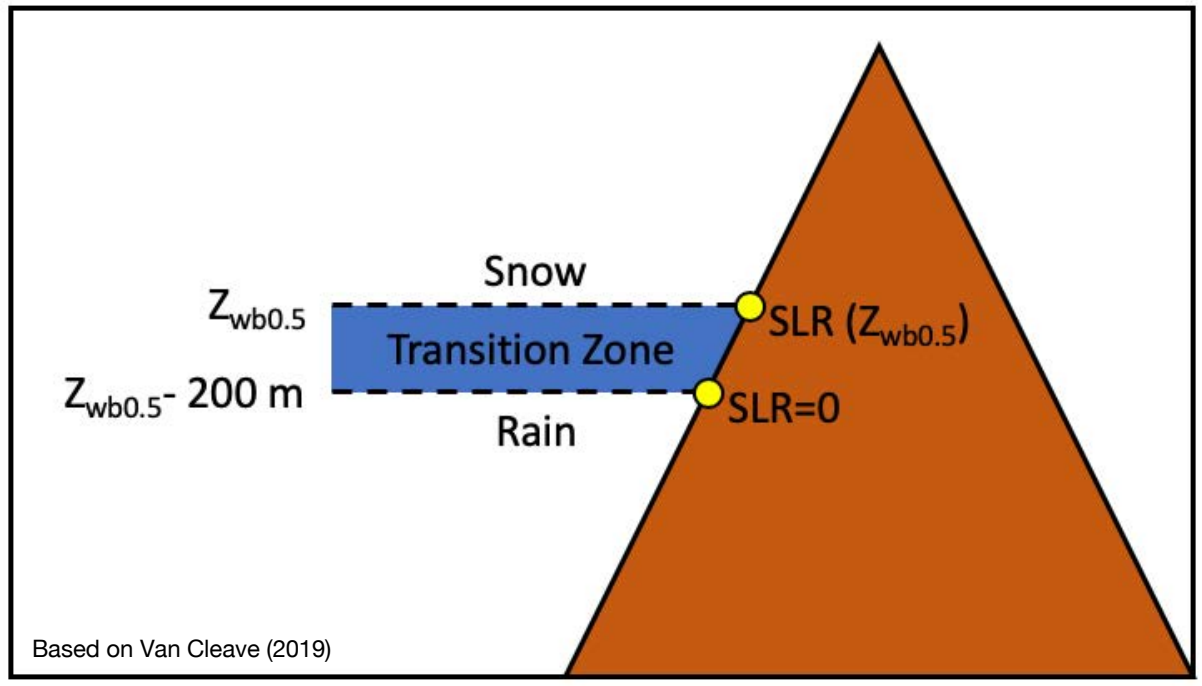




Random Forest with more levels and variables even better but computational cost higher
See: Veals et al. (2025, submitted)

# Step 3: Snow Level

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

# Simple Is as Simple Does

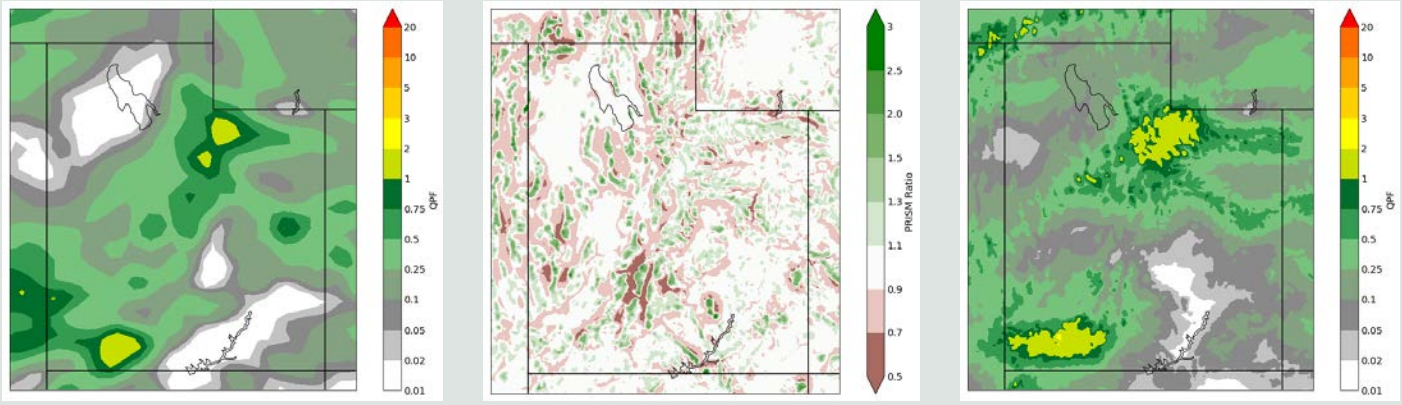



**Currently not dealing with warm noses/mixed precipitation (issue in some PacNW areas)**
**Currently not dealing with on-the-ground melt and settlement in near 0ºC environments**
**Given low vertical res of available GEFS/ENS grids, will probably need ML approach**

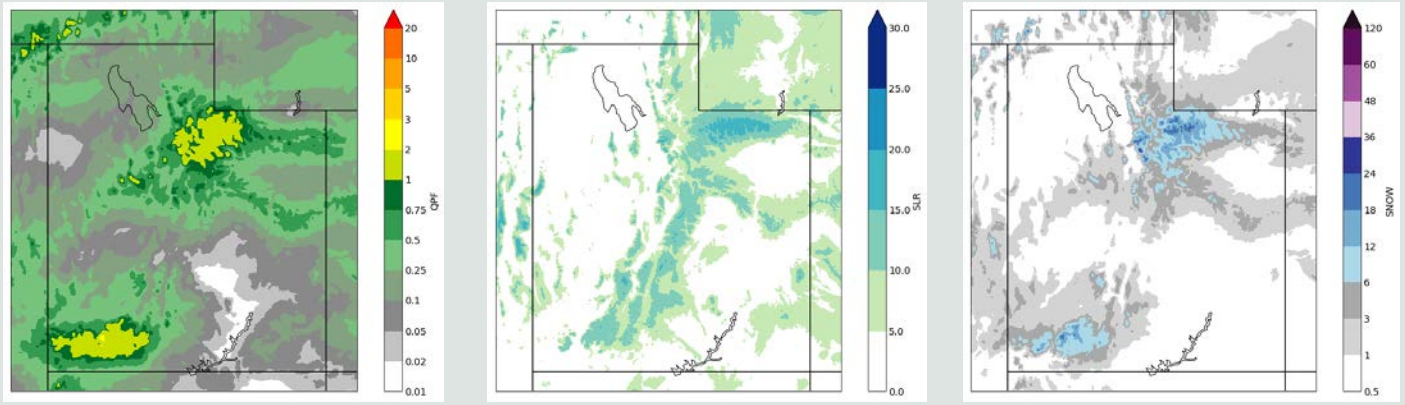
# Putting It All Together

Photo: Jim Steenburgh

Model QPF X PRISM Ratios = Downscaled 800 m QPF



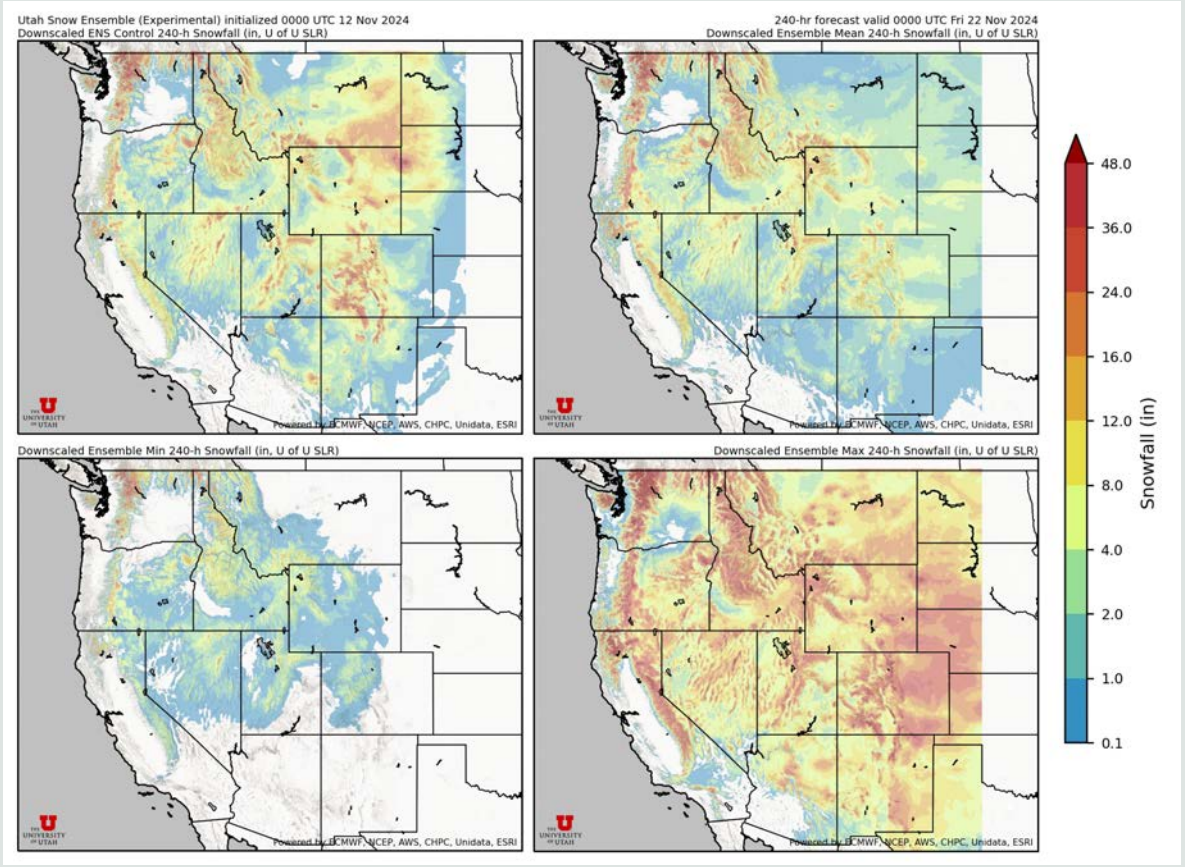

Downscaled 800 m QPF X Downscaled MLR SLR = Downscaled 800-m Snow




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**



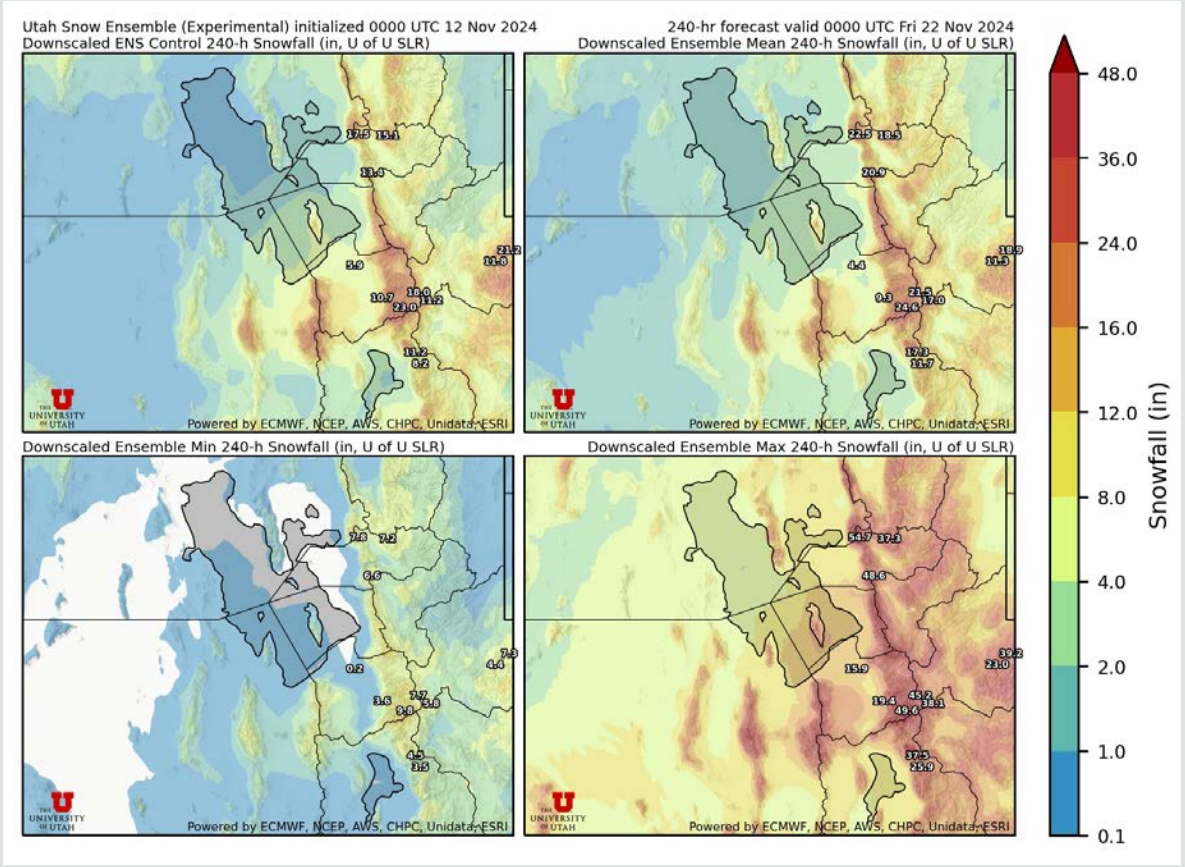

**Mean 240-h Snowfall**

**Min 240-h Snowfall**

**Max 240-h Snowfall**

# Utah Snow Ensemble

**CTL 240-h Snowfall**



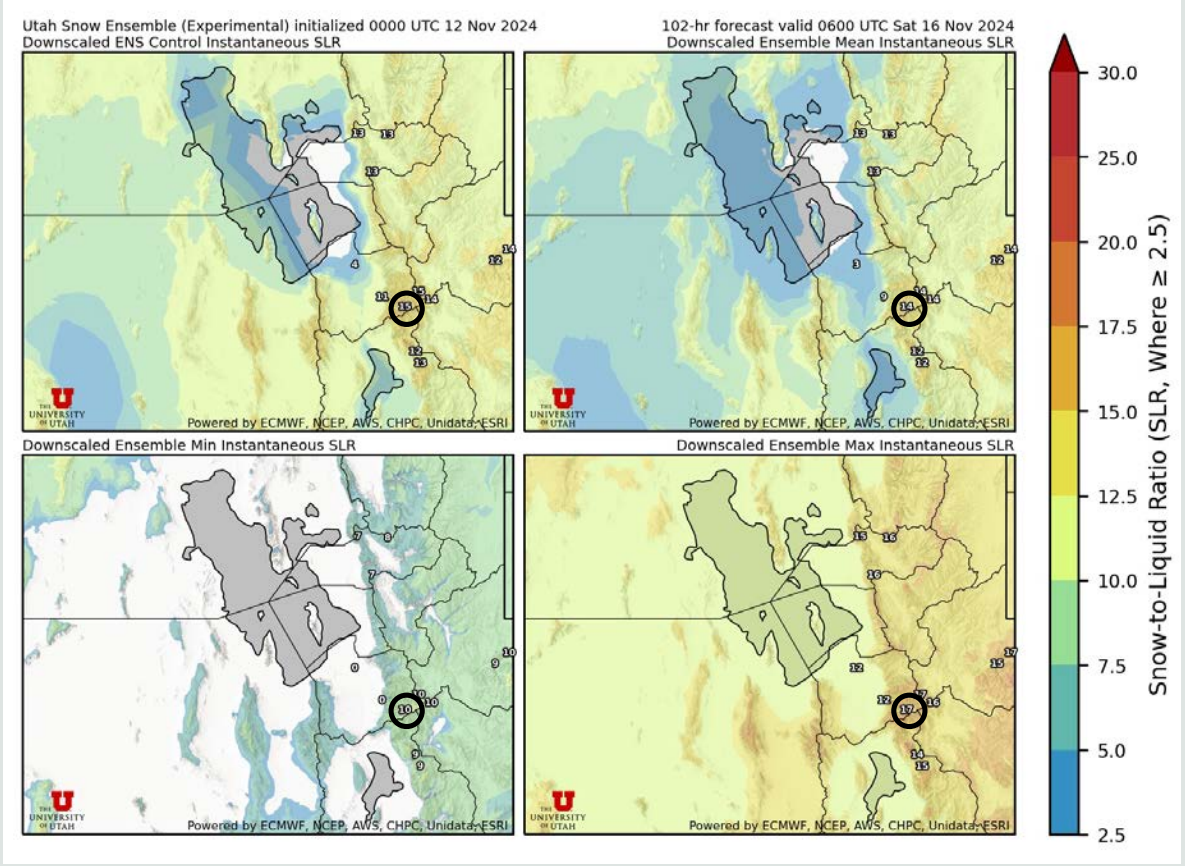

**Mean 240-h Snowfall**

**Min 240-h Snowfall**

**Max 240-h Snowfall**

# Utah Snow Ensemble

**CTL 102-h SLR**

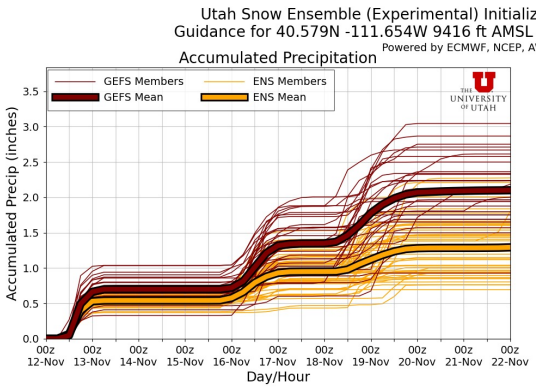


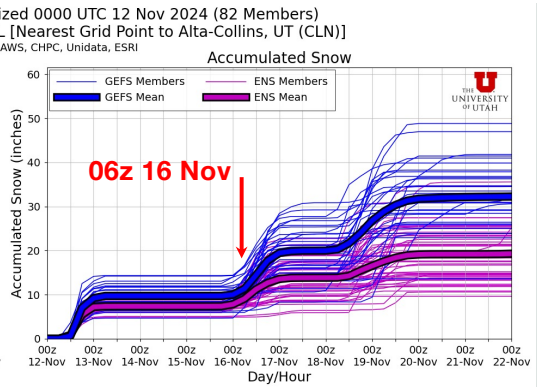

**Mean 102-h SLR**

**Min 102-h SLR**

**Max 102-h SLR**

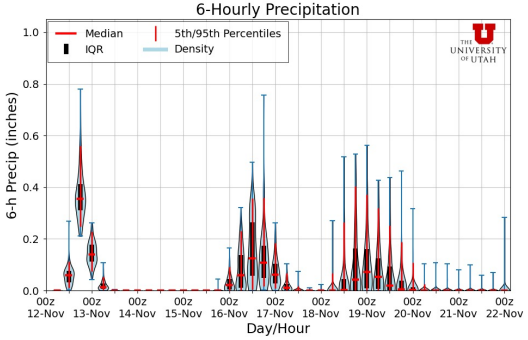
**Accumulated Precip**

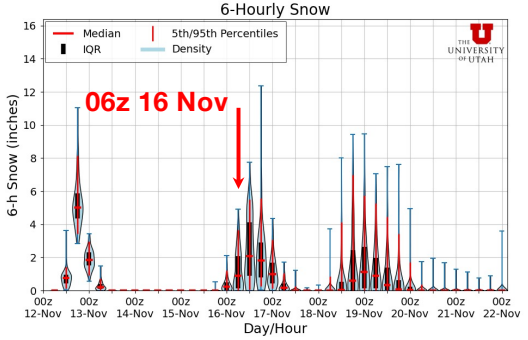



**Accumulated Snow**

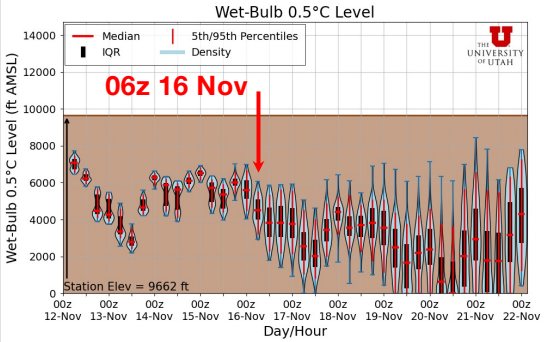
**6-h Precip**

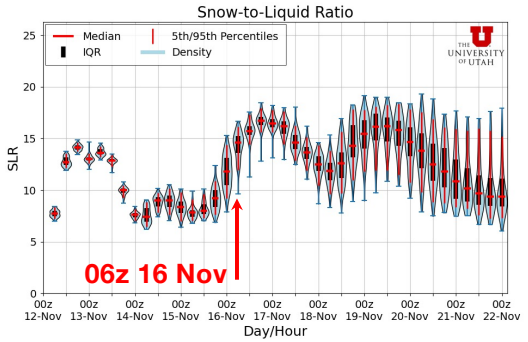



**6-h Snow**

**Probabilistic 0.5°C Level**

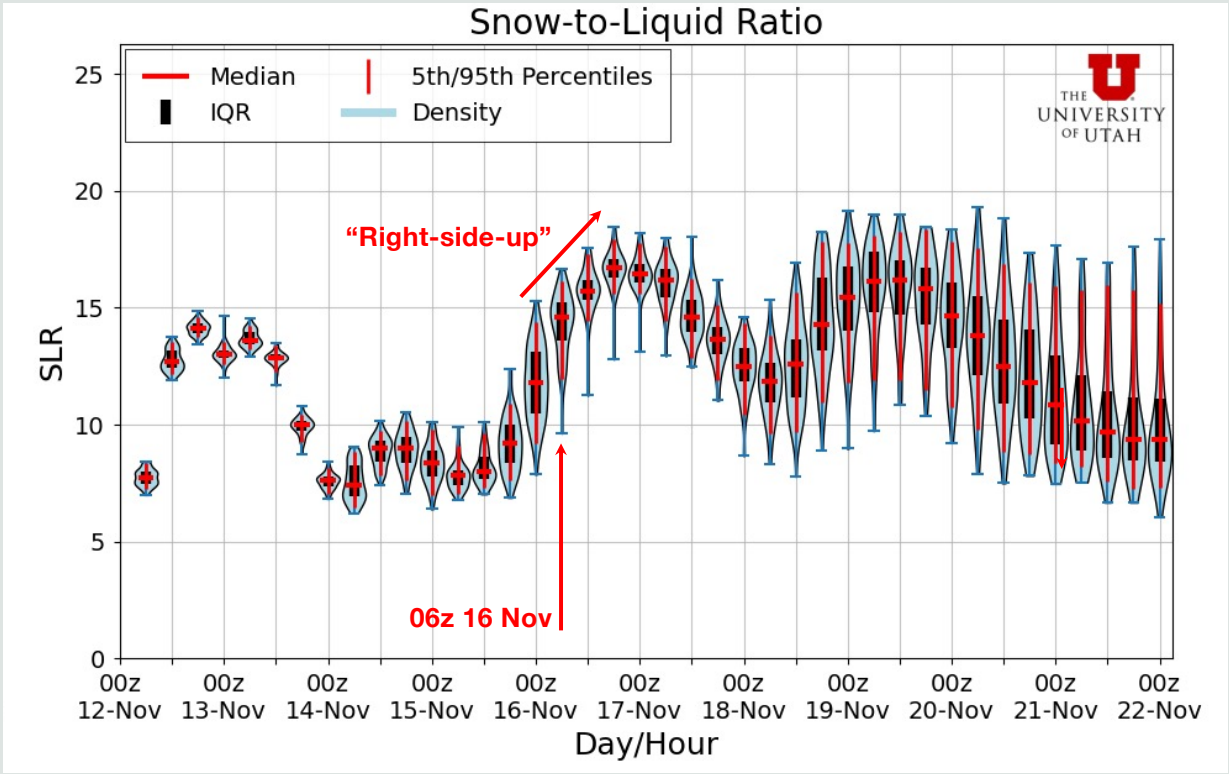


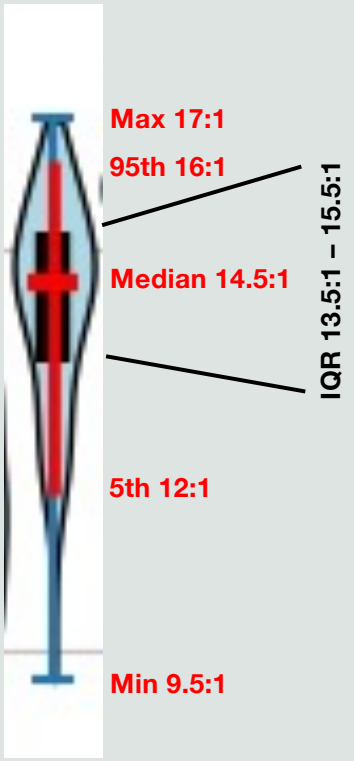




**Probabilistic SLR**

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

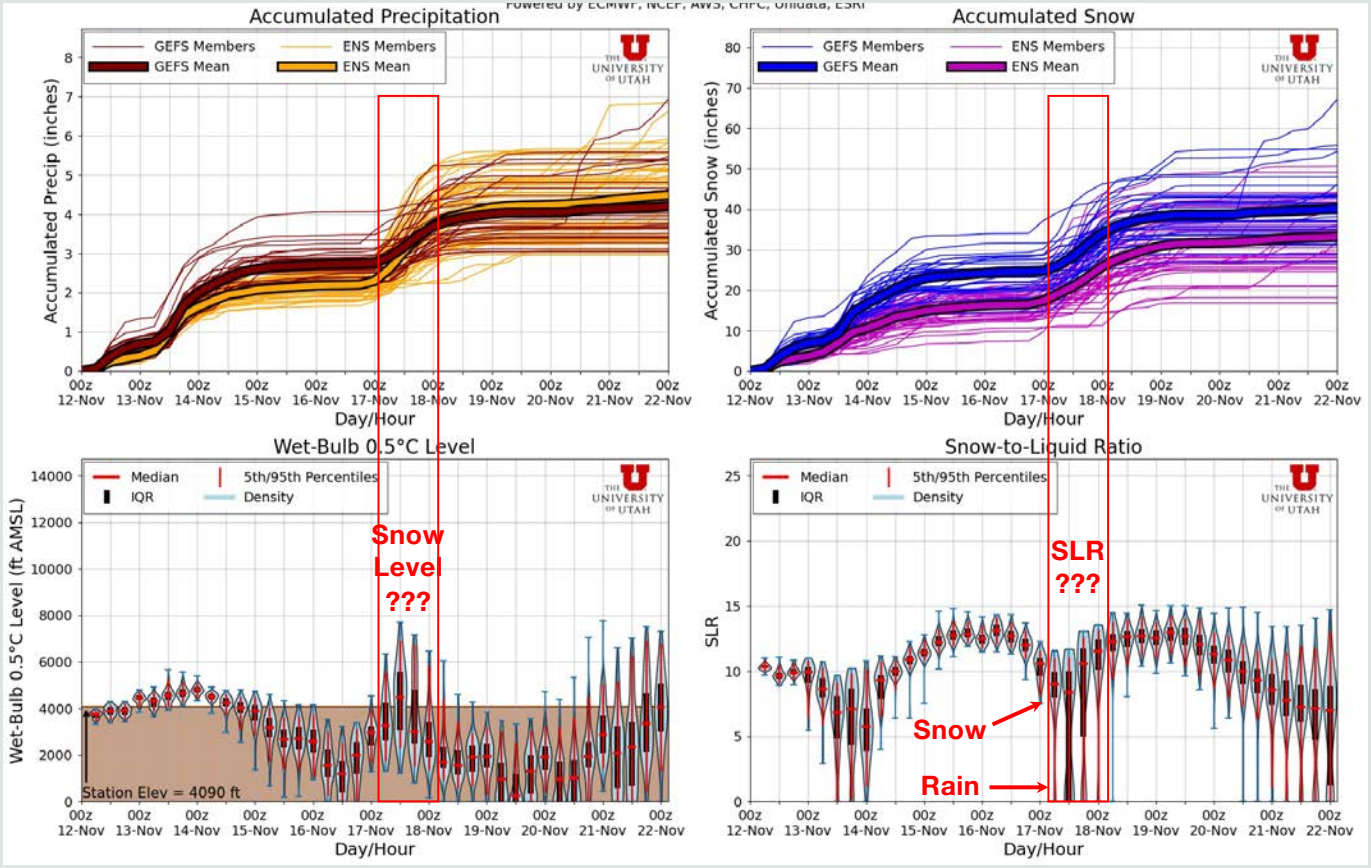
# SLR Probabilities




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**

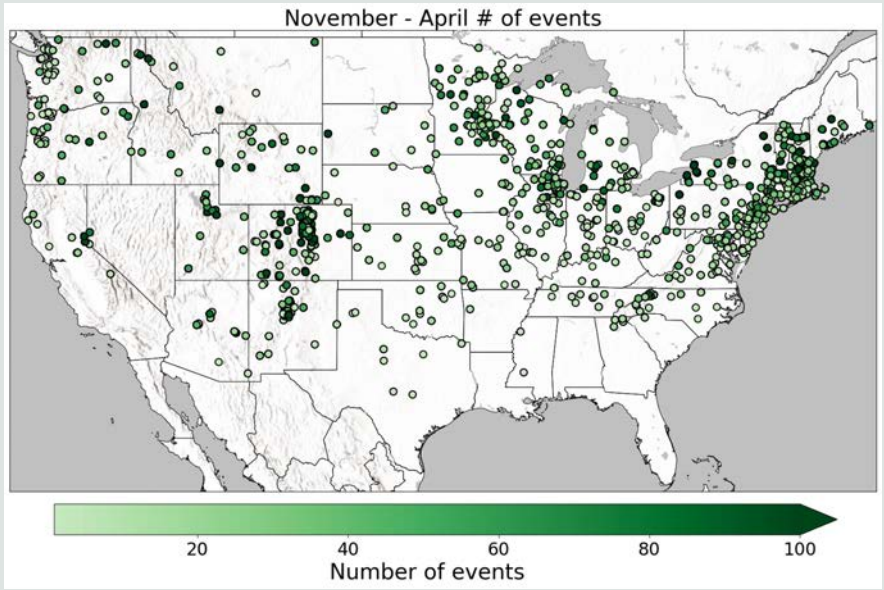
***"The success of our avalanche forecasting at UDOT has benefited tremendously from the research work completed…at the University of Utah. The winter precipitation research and visualization tools available at weather.utah.edu have become essential tools for our program."***
**– Steven Clark, UDOT Avalanche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

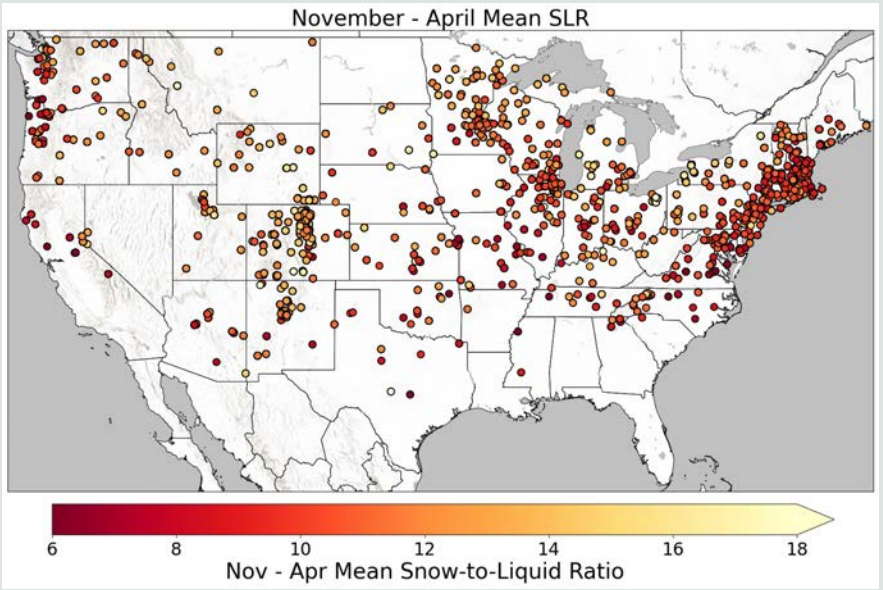
**weather.utah.edu: 23 million hits in past year**

# 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

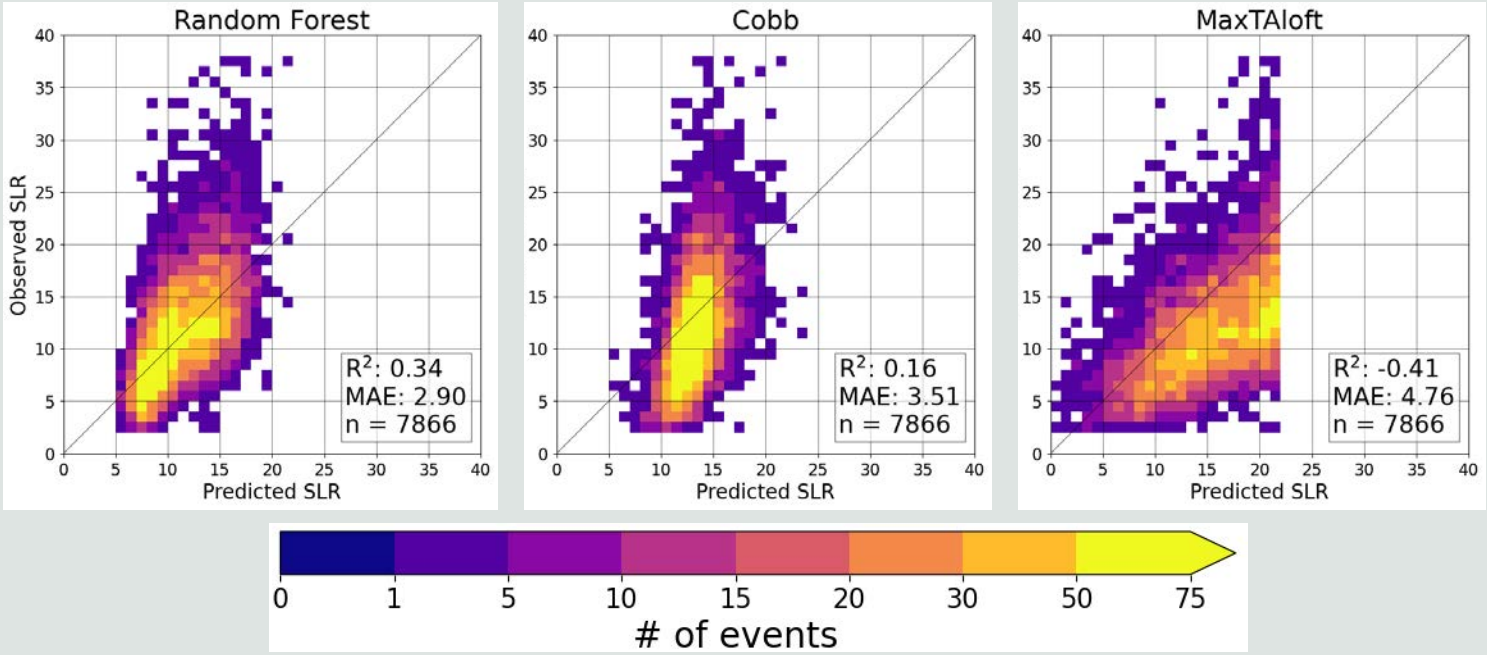
- **Random forest (RF): Aggregates predictions from an ensemble of decision trees to make a deterministic prediction**
- **Trained with ERA5 Reanalysis and CoCoRAHS 24-h SLR obs; 60/40 train/validate split**
- **Training period: December 2000 to April 2022**
- **Testing period: November 2022 to April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

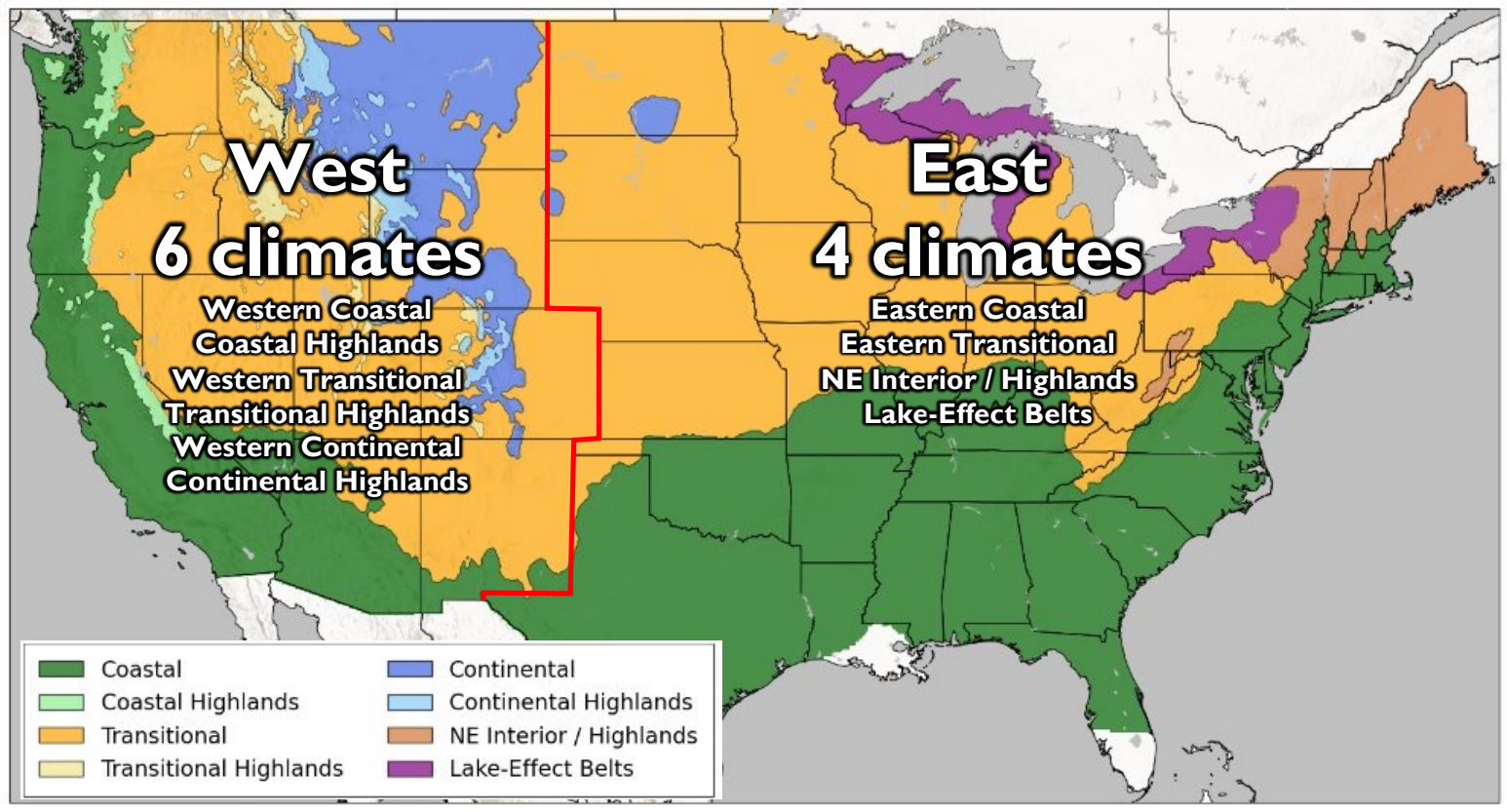
**Most predictors were chosen based on results from previous studies [Roebber et al. (2003); Cobb and Waldstreicher (2005); Alcott and Steenburgh (2010)]**

# CONUS-Wide Performance



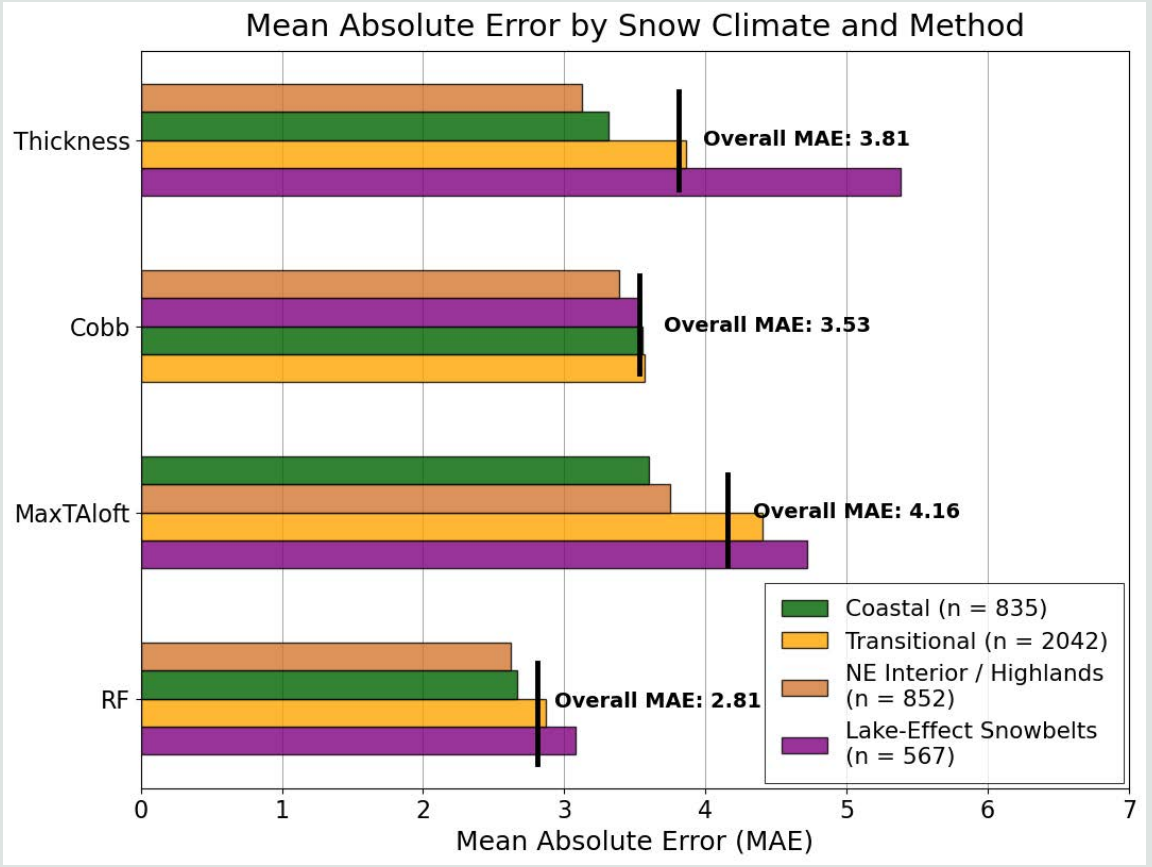
# CONUS Snow Climates

**Based on NOHRSC=Derived Climatology and Baxter et al. (2005) SLR Climatology**

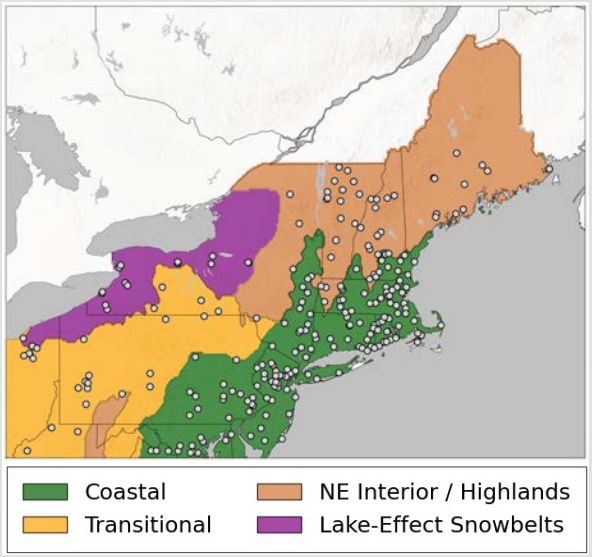


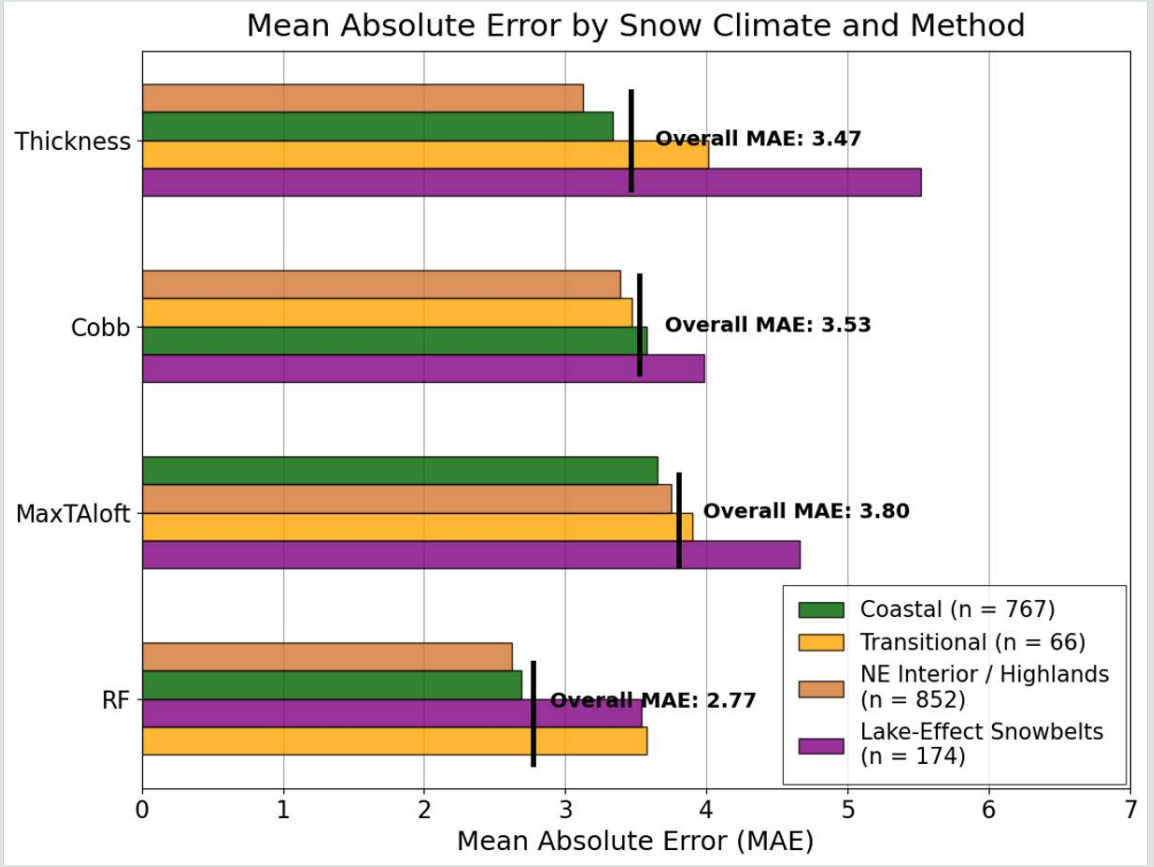
# Eastern CONUS

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



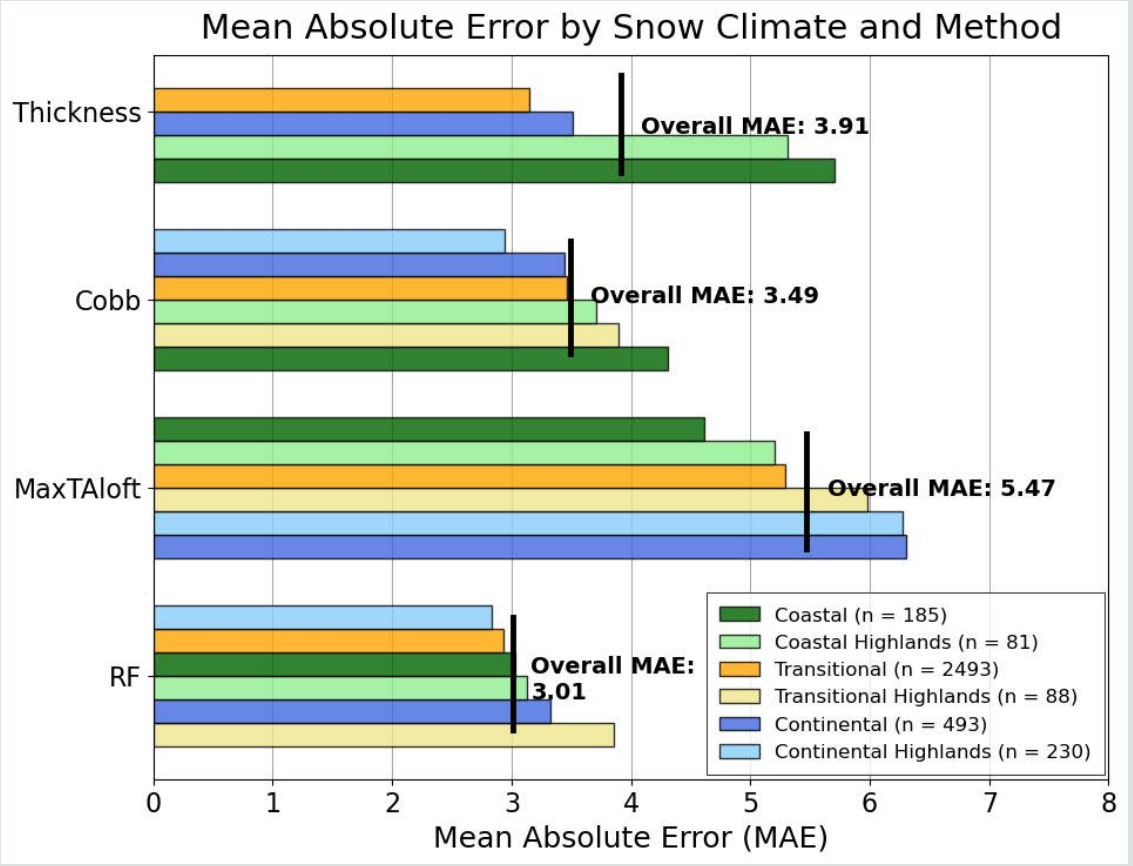
# Northeastern CONUS



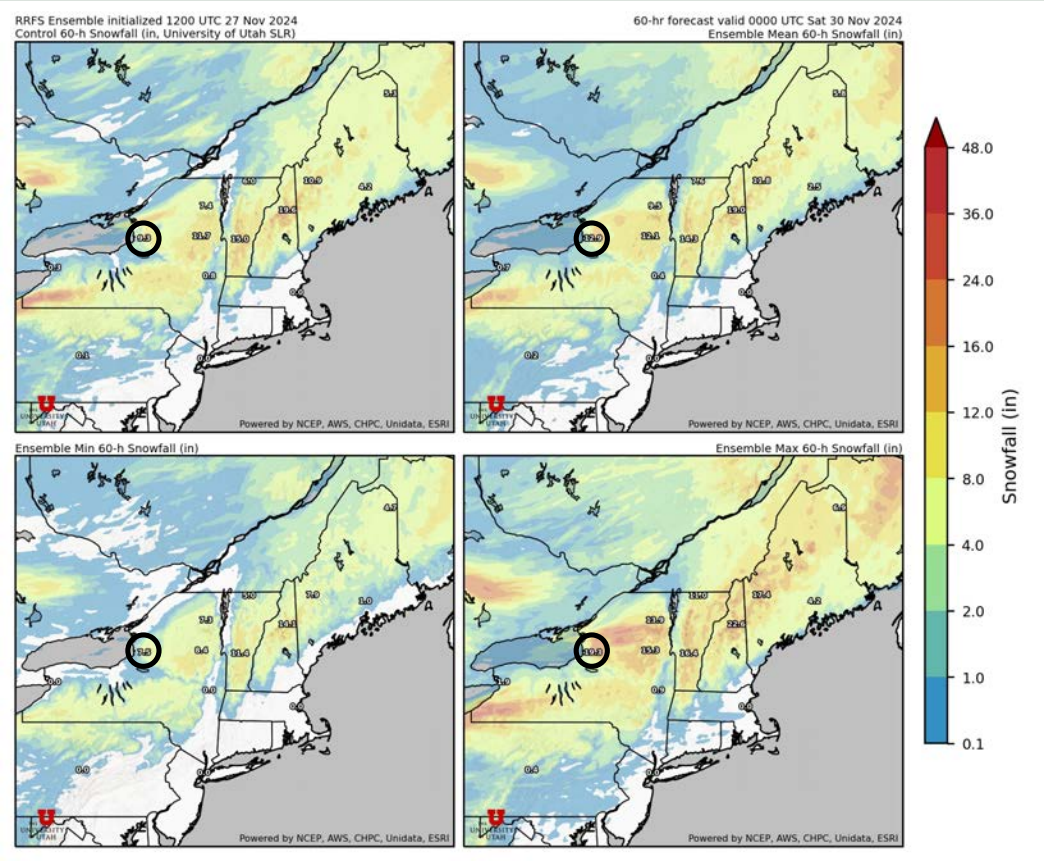
# Western CONUS

- **RF exhibits lowest MAE for all snow climates**
- **Only Cobb produces lower MAEs for west than east**



# RRFS

**CTL 60-h Snowfall**




**Mean 60-h Snowfall**

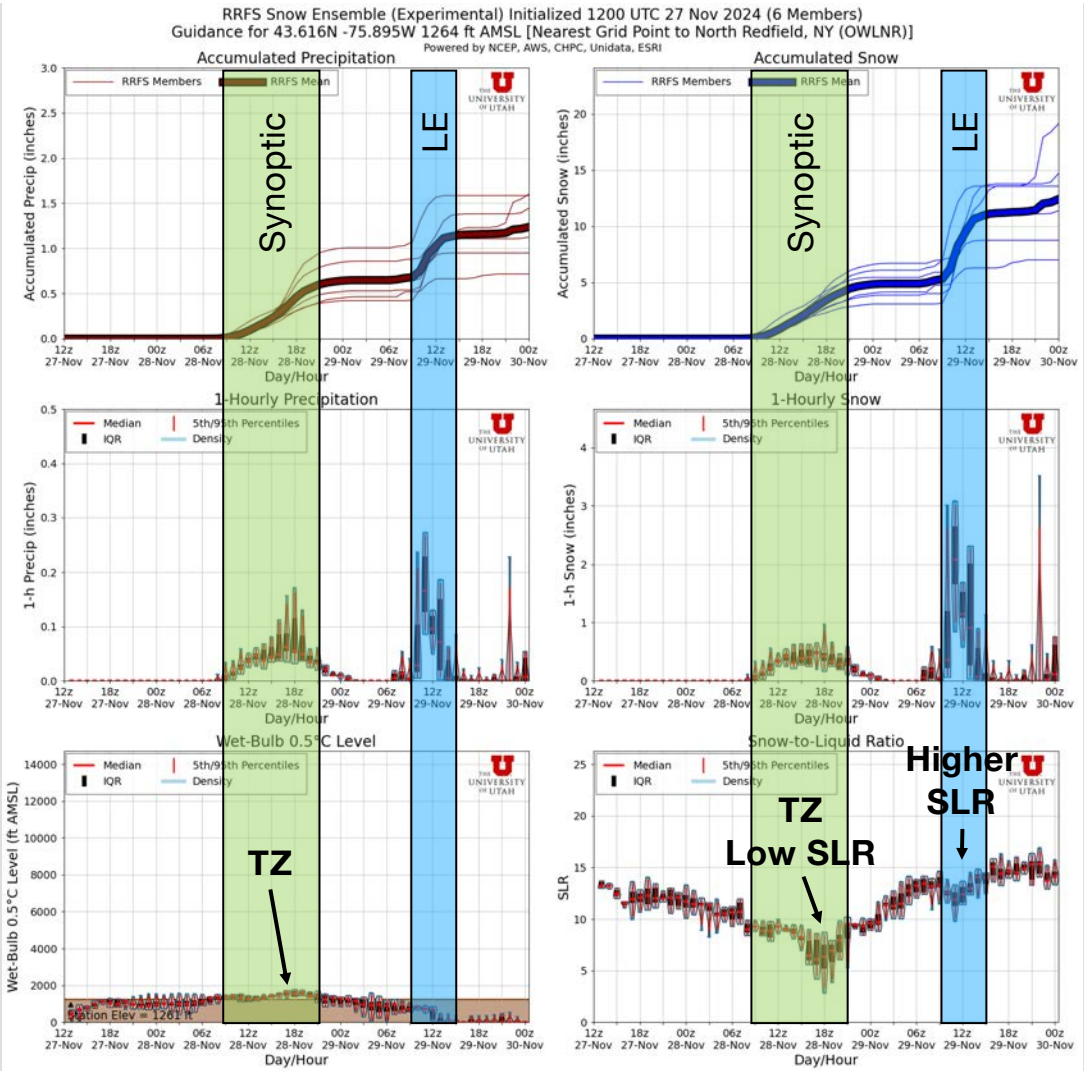
**Min 60-h Snowfall**

**Max 60-h Snowfall**

**Accumulated Precip**

**1-h Precip**

**Probabilistic 0.5°C Level**




**Accumulated Snow**

**1-h Snow**

**Probabilistic SLR**

# 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 were also producing CONUS-wide SLR & snowfall forecasts from the RRFS ensemble
- Trying to figure out how to pivot for WWE
- See http://weather.utah.edu for forecasts