Improving Snow-to-Liquid Ratio Forecasts in the Western United States

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Winter Precipitation Forecasts

- Challenges in addition to quantitative precipitation forecasts (QPF):
  - Precipitation type
  - Snow-to-liquid ratio (SLR)
  - Snowfall rates and amounts
  - Snow level
  - Wind transport
- Civil and economic impacts can be significant, disrupting travel, impacting commerce and tourism, and causing widespread property damage

Objectives

- Improve accuracy of snowfall forecasts in the western U.S. through post-processing using a novel Snow-to-Liquid Ratio (SLR) algorithm
- Produce snowfall forecast products at a resolution better able to account for variability in complex terrain (800 m)
- Provide SLR forecast tools to be evaluated as a part of the NOAA-HMT Winter Weather Experiment and potential operational applications

Snow-to-Liquid Ratio (SLR)

- Used to convert the QPF to a quantitative snowfall forecast (QSF)

- Methods in operational use (combined using expert/equal weighting):
  - Apply a fixed value (10:1)
  - Based on highly simplified univariate statistical relationships
  - Based in climatology derived from NWS COOP observing sites

- Significant variability in SLR may exist:
  - Over short distances in complex terrain
  - Within a single event
  - Event-to-event
  - Deviations from climatology may be large

Controls on SLR

- Crystal type and size
- Riming
- Aggregation
- Wind transport
- Melting or sublimation
- Rain on snow
- Metamorphism and/or external compaction

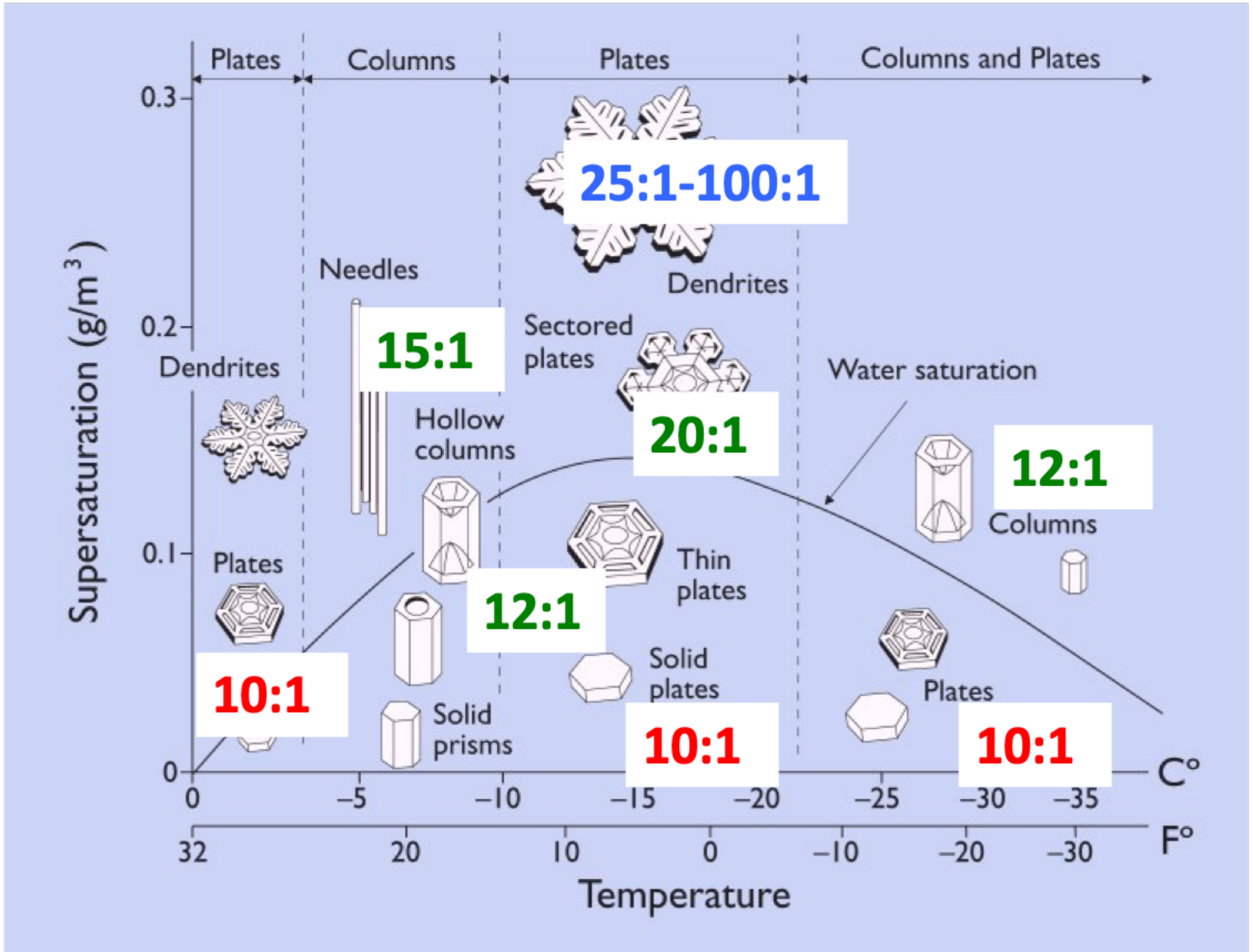
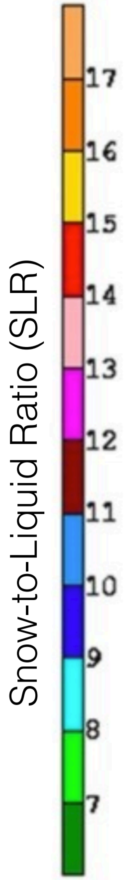
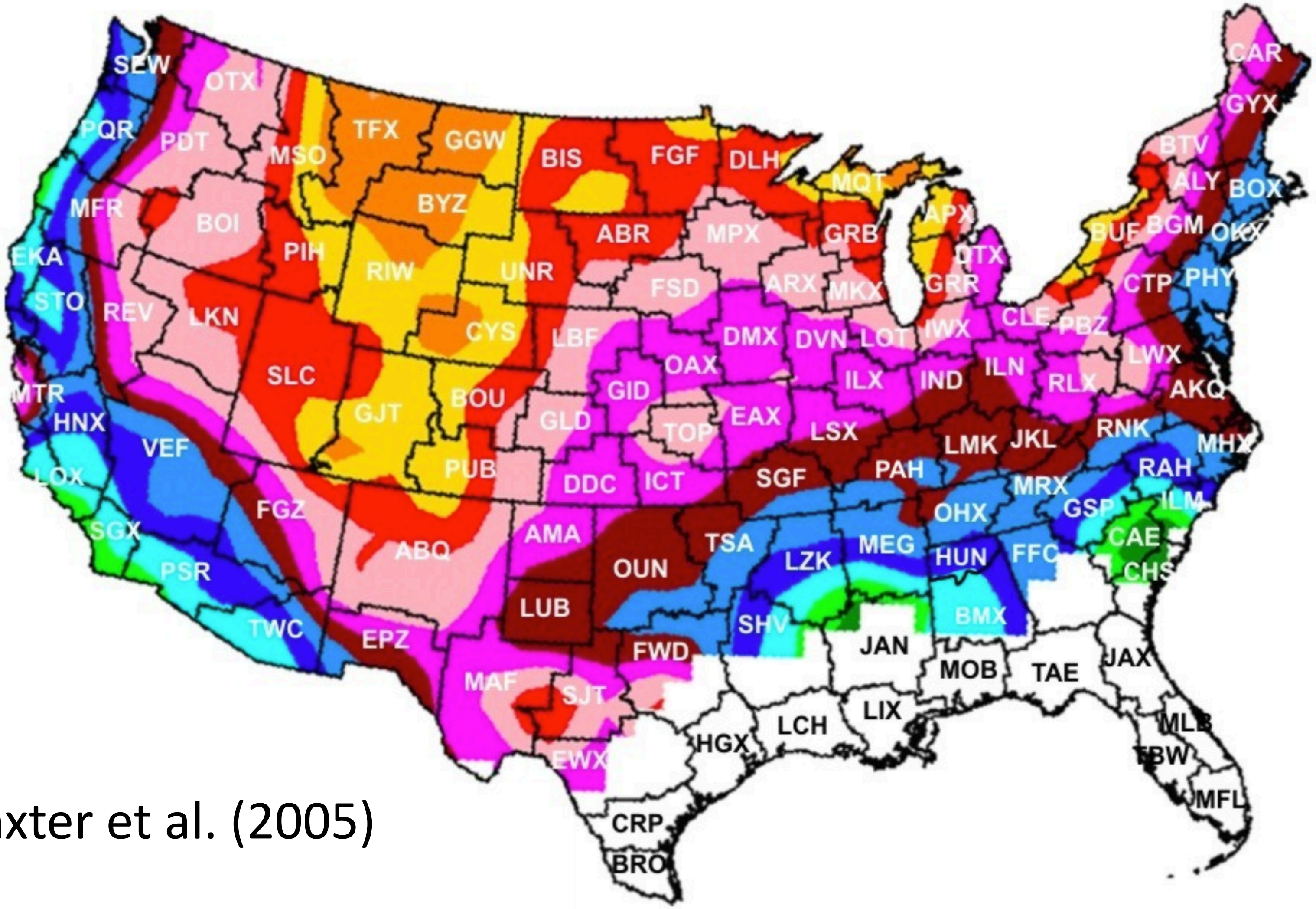


Image: snowcrystals.com; SLR based on Power et. al. 1964, Dubé 2003, Cobb 2006

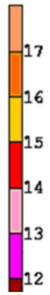
SLR Climatology





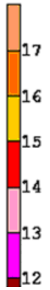
Baxter et al. (2005)

Monterey, CA



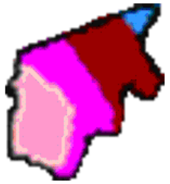
Avg SLR: 14.1
Standard Dev: 11.4
75th Percentile: 18.7
50th Percentile: 10.3
25th Percentile: 4.8

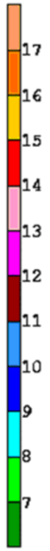
Salt Lake City, UT



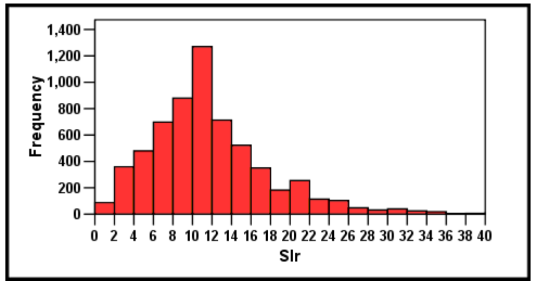
Avg SLR: 14.2
Standard Dev: 7.0
75th Percentile: 17.5
50th Percentile: 13.0
25th Percentile: 9.8

Baltimore/Washington





Avg SLR: 11.8
Standard Dev: 6.4
75th Percentile: 14.5
50th Percentile: 10.5
25th Percentile: 7.8



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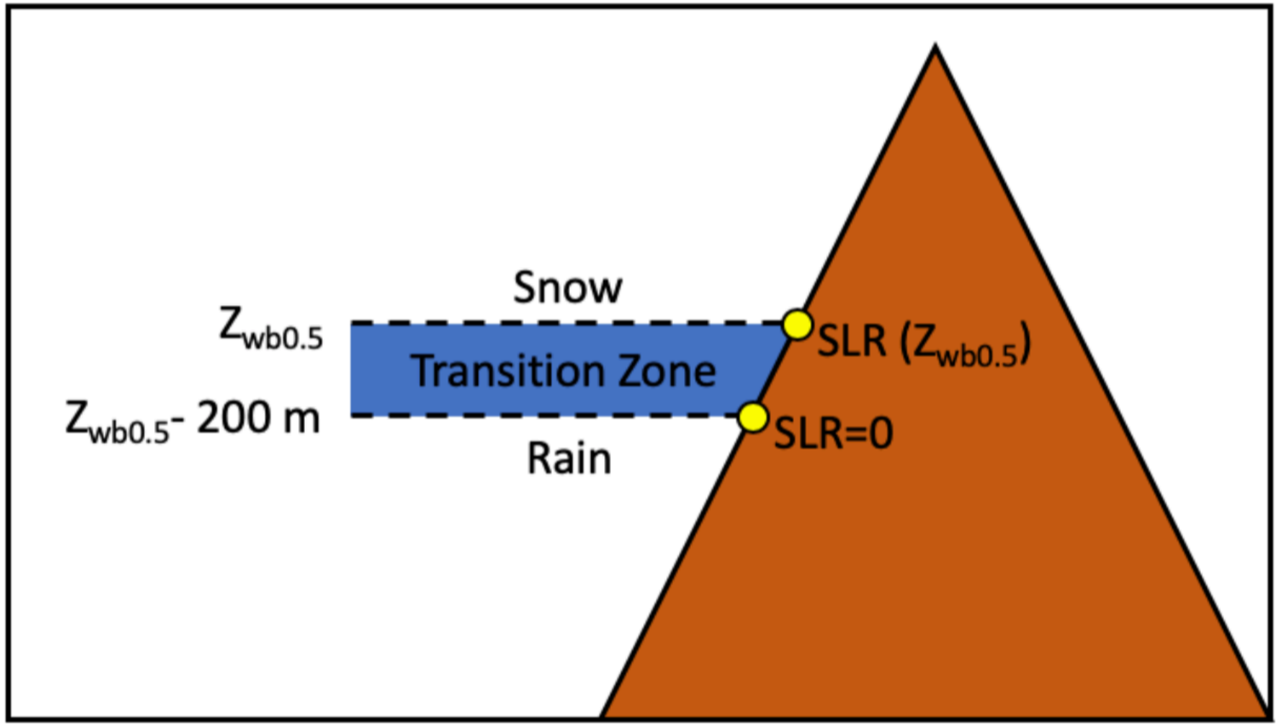
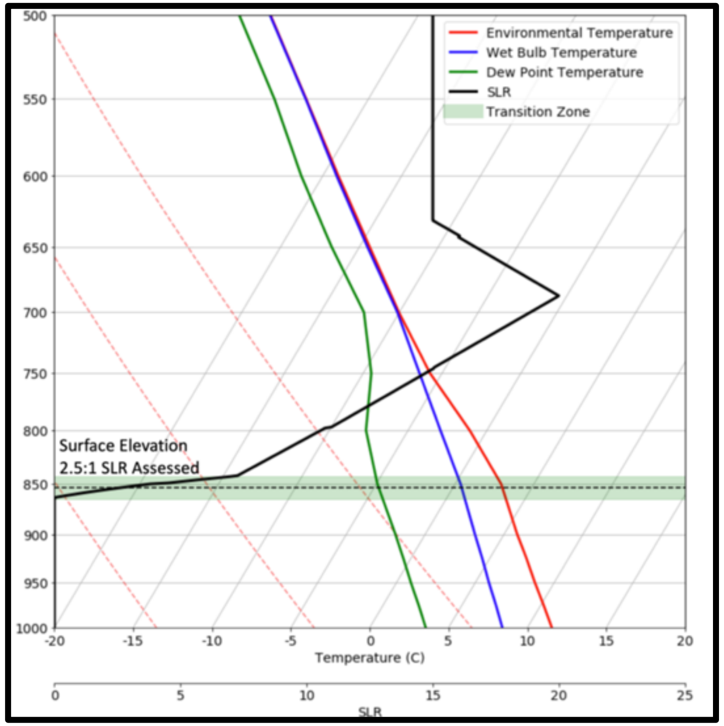
Simple Snow Level for SLR Application

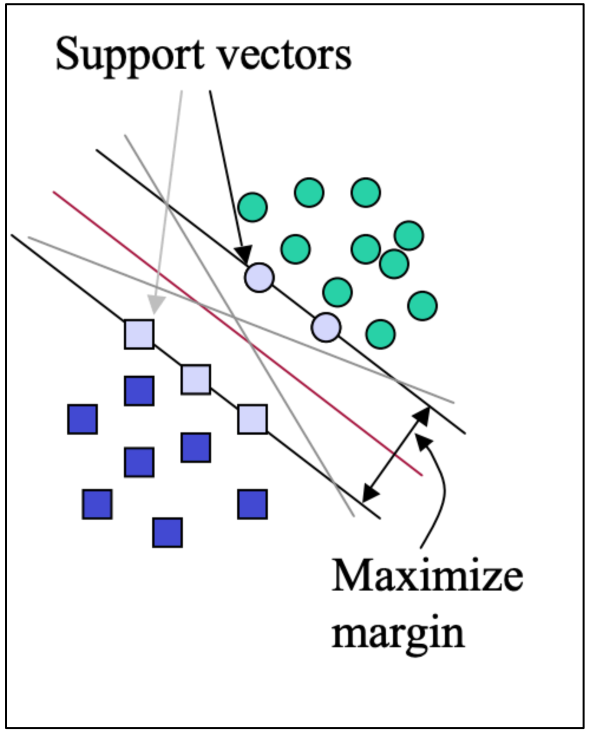
- Assess the height of the 0.5°C Wet Bulb Temperature
- Apply SLR above 'snow level' with linear reduction in transition zone





Modeling SLR with Support Vector Regression

- Support Vector Regression (SVR)
  - Classifies points in a constructed multidimensional space
  - Strong performance on small-to-medium sized datasets



- Training the model:
  - Use a set of predictors (ERA5 grids) and target values (SLR observations)
  - Trained on minimizing Mean Squared Error

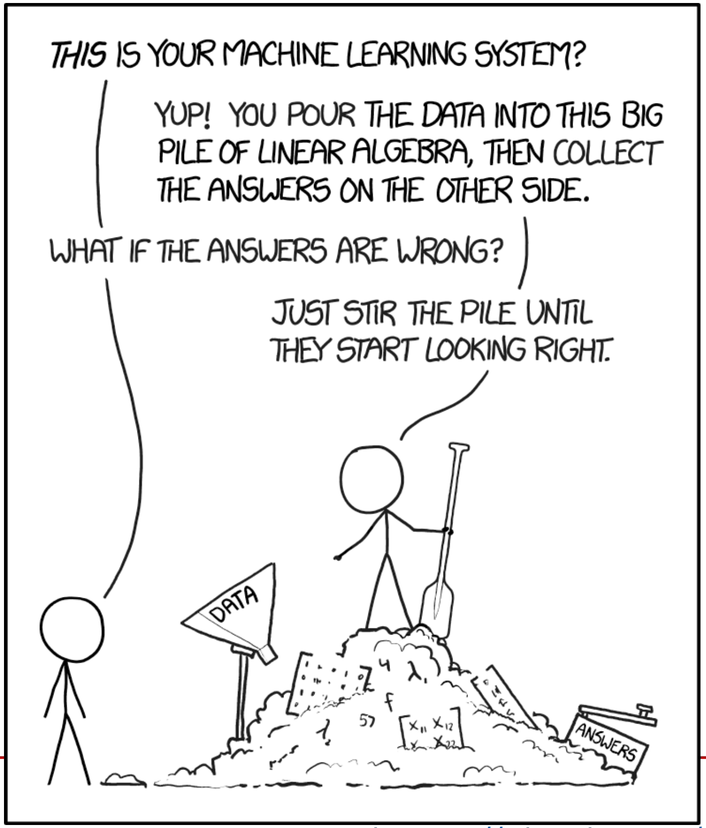
- Generalize the model, apply to the GFS

Modeling SLR with Support Vector Regression

- Observations:
  - High-elevation snow safety site in northern Utah's Wasatch mountains
  - Manual 12-hour accumulated snowfall and snow water equivalent (SWE)

- Train/Test Set:
  - Model: ERA5 Reanalysis (0.28°)
  - 20 Cool Seasons (1999 – 2019)
  - n=1915 events

- Reforecast/Verification Set:
  - Model: GFS (0.25°)
  - 3 Cool Seasons (2016 – 2019)
  - n = 536 events



https://xkcd.com/

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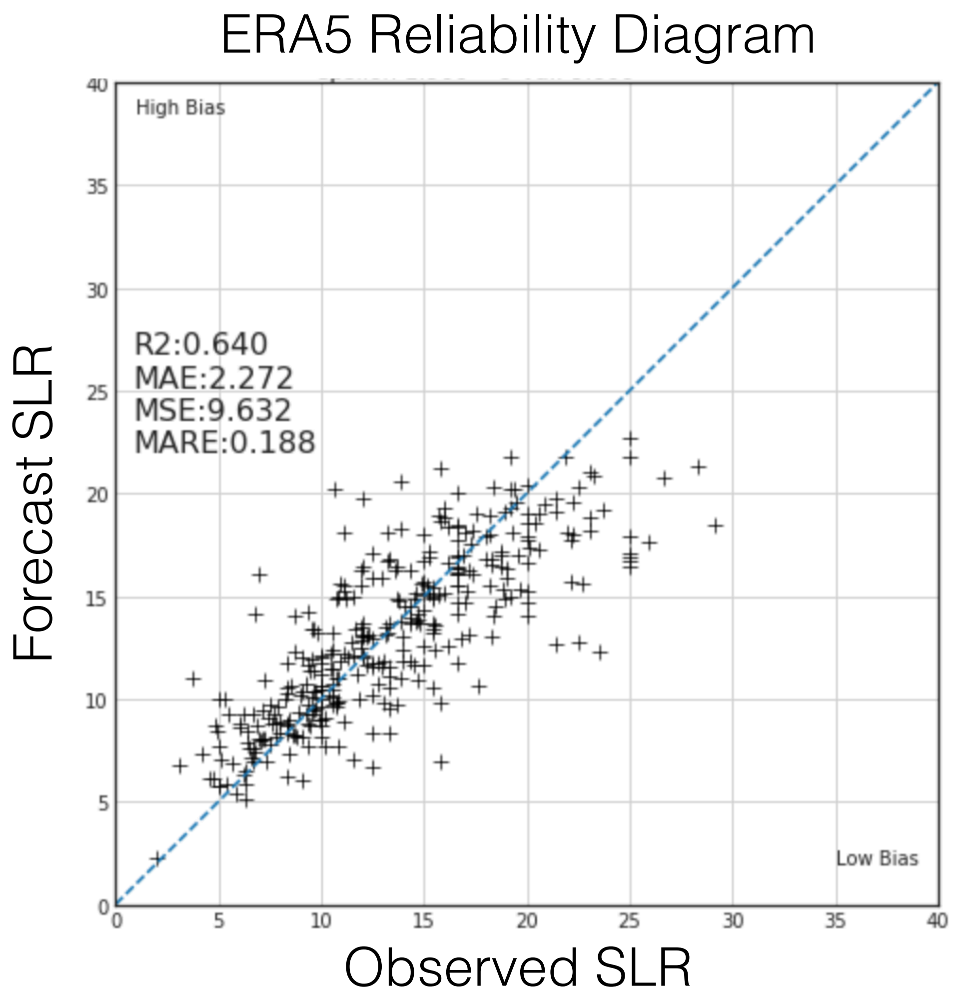
Available Predictors

Available Predictors in ERA5 and GFS		
Temperature	Geopotential Height	CAPE
Relative Humidity	Absolute Vorticity	Boundary Layer Height
U, V Wind	Vertical Velocity	Sea Level Pressure
Wind Speed	Wind Direction	Surface Pressure

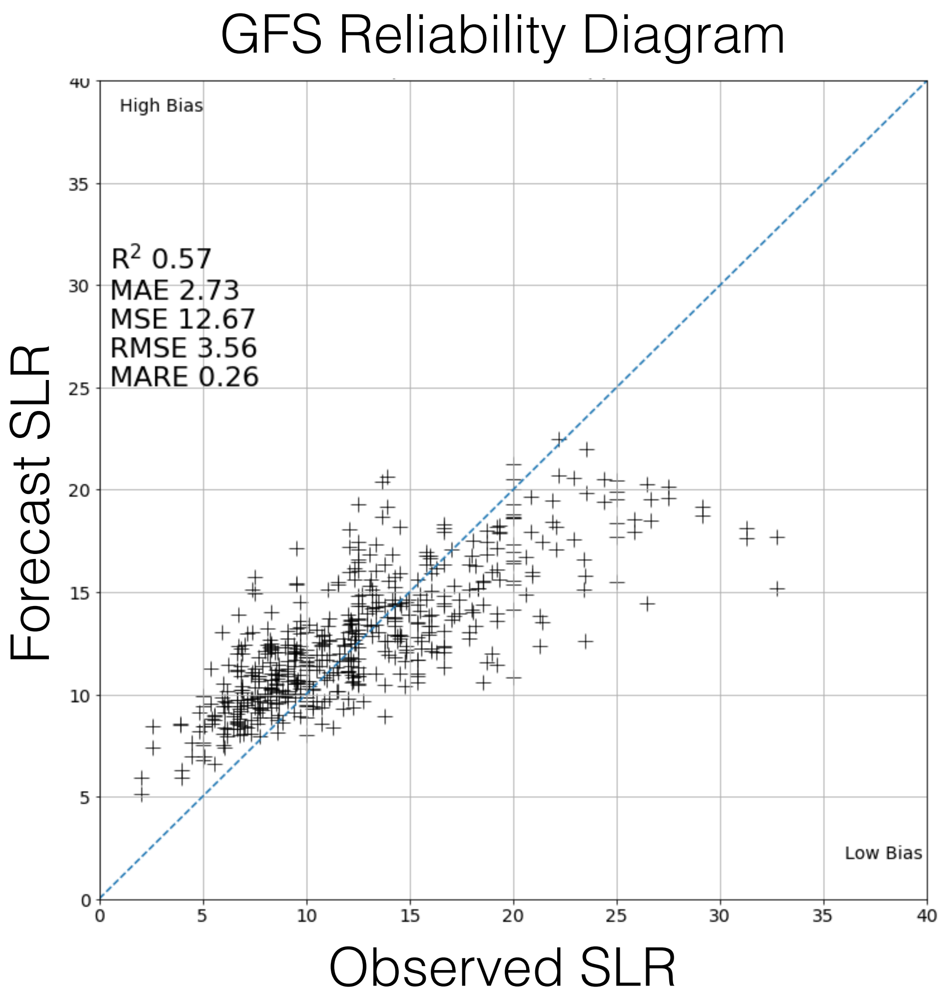
- Perfect prog technique (Train on ERA5, apply to GFS)
- GFS grid point elevation and mean geopotential height is used to determine the lowest above-ground pressure level, predictors below this level are not used

Results: SVR SLR Model Performance

Train/Test:



Verification



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Results: Model Performance Comparison

- All metrics based on verification set for a single high-elevation site in northern Utah
- Must consider multiple metrics in evaluating model performance

Model	RMSE Root Mean Square Error	MAE Mean Absolute Error	MAPE Mean Absolute Percent Error	R^2
SVR[1]	3.56	2.73	26%	0.57
Alcott[2]	6.60	6.60	65%	0.51
RAPv4/HRRRv3[3]	6.40	5.00	38%	0.28
Kuchera	4.93	3.97	36%	0.16
Baxter[4]	6.03	5.06	58%	0.03
NWS Lookup Table[5]	6.27	4.39	35%	NA
Fixed 10:1	6.00	4.40	35%	NA

1 Preliminary results, further tuning needed
2 Alcott and Steenburgh (2010)
3 Benjamin et al. (2020)
4 Baxter et al. (2005)
5 Department of Commerce (1996)

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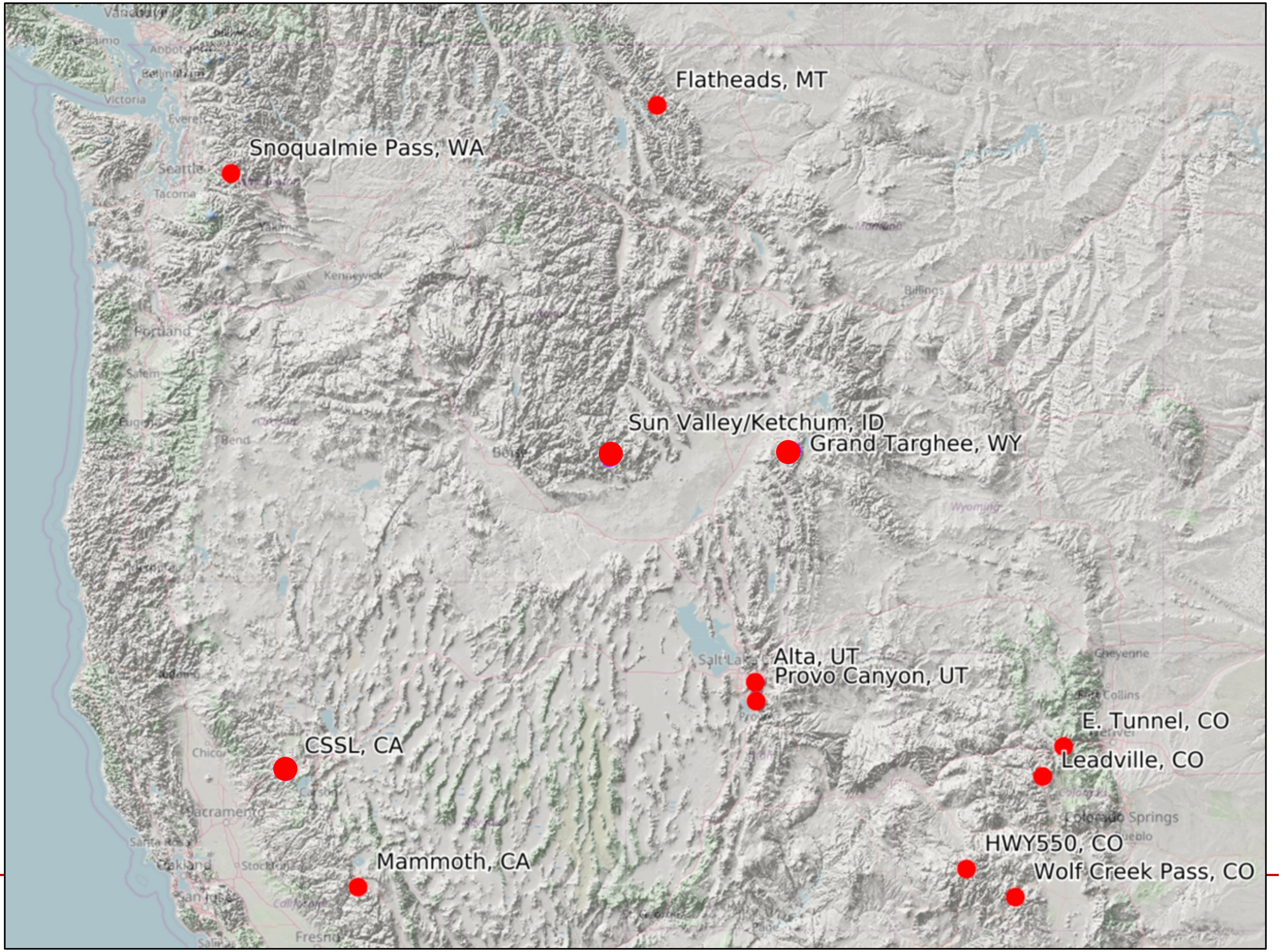
Next Steps: Expand Across Western U.S.

- High-quality snowfall observations are available from a number of snow safety sites

- Develop regionally-trained SVR SLR models from a variety of sites to determine the degree of improvement over a generally-trained and applied west-wide model



WPC-HMT Winter Weather Experiment

- Provided 800 m downscaled deterministic (GFS, NAM) and probabilistic (NAEFS, SREF) SLR and snowfall forecast grids based on simplified Alcott and Steenburgh (2010) method

- Products were generally well-received, favored in subjective verification exercises over the Intermountain West
  - Majority of improvement noted at higher elevations

- Provide SLR and snowfall forecast grids for regionally-trained, SVR-based algorithm across the western U.S.
  - Push updates to University of Utah web products

Summary / Q&A

- Accurate Snow-to-Liquid Ratio (SLR) forecasts over complex terrain are critical to winter precipitation forecasts, directly affecting snowfall rates and accumulations

- Climatological or fixed SLR are insufficient in representing the degree of variability present over complex terrain, from event-to-event, and over the course of long-duration single events

- Support Vector Regression (SVR) based SLR outperforms a number of existing methods verified at a high-elevation site in northern Utah

- 2020-21 WPC-HMT Winter Weather Experiment will evaluate the performance of this novel SLR forecast technique

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For current applications, see Poster #19:
Downscaled Probabilistic Snowfall Forecast Products for the Western United States