Improved Snow-to-Liquid-Ratio Forecasts from Operational Models in the Western US

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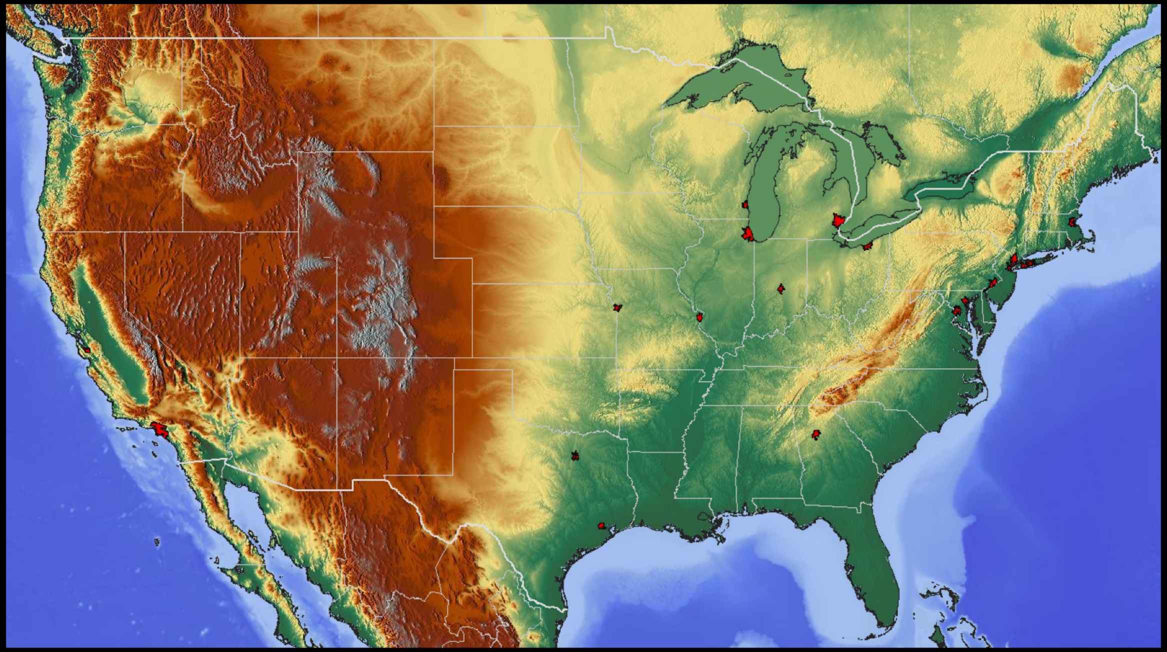
Motivation

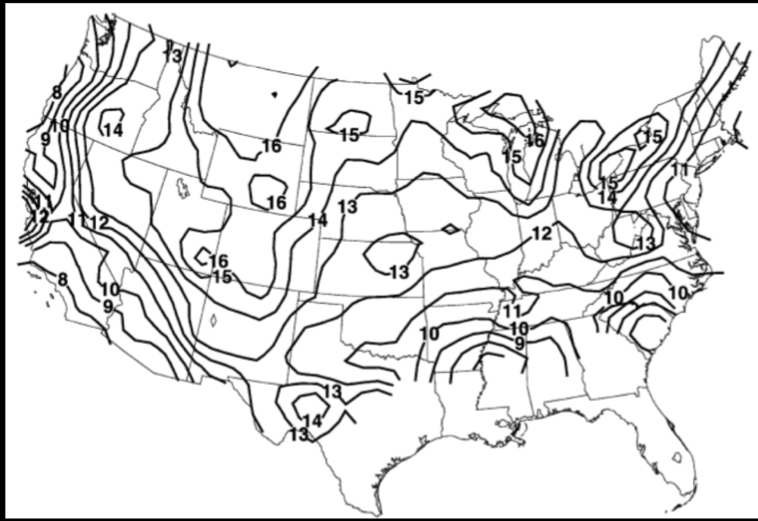
An accurate snowfall forecast requires both an accurate QPF and an accurate snow-to-liquid-ratio (SLR)

SLR techniques that are currently in use are not very skillful, particularly over the Western US

Our work seeks to improve SLR forecasts first over the Western US, and then over the entire CONUS

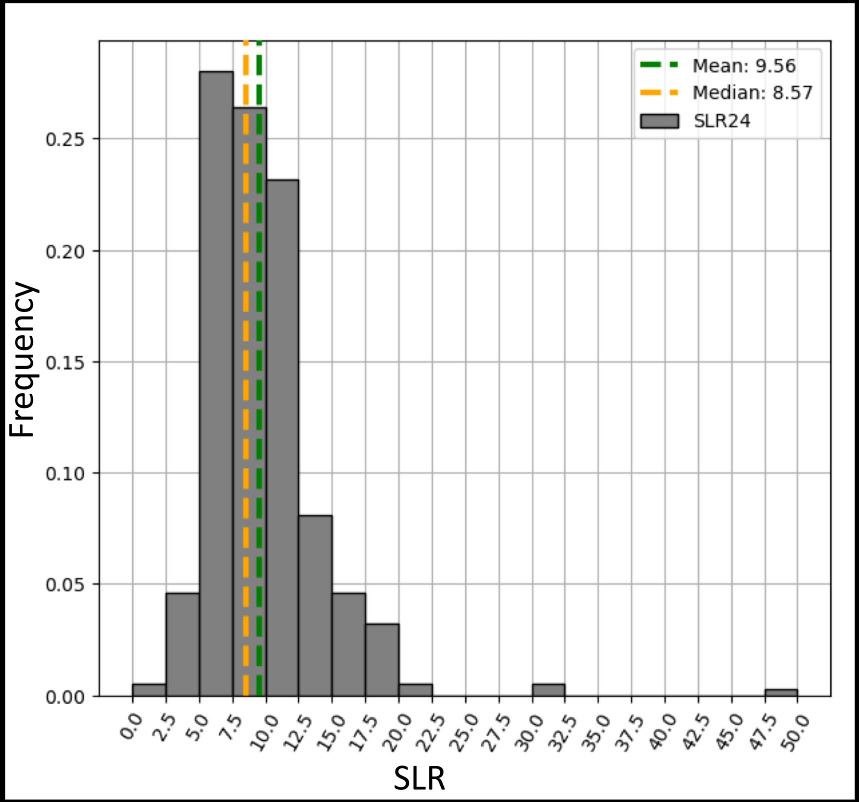


Snow-to-Liquid Ratio (SLR)

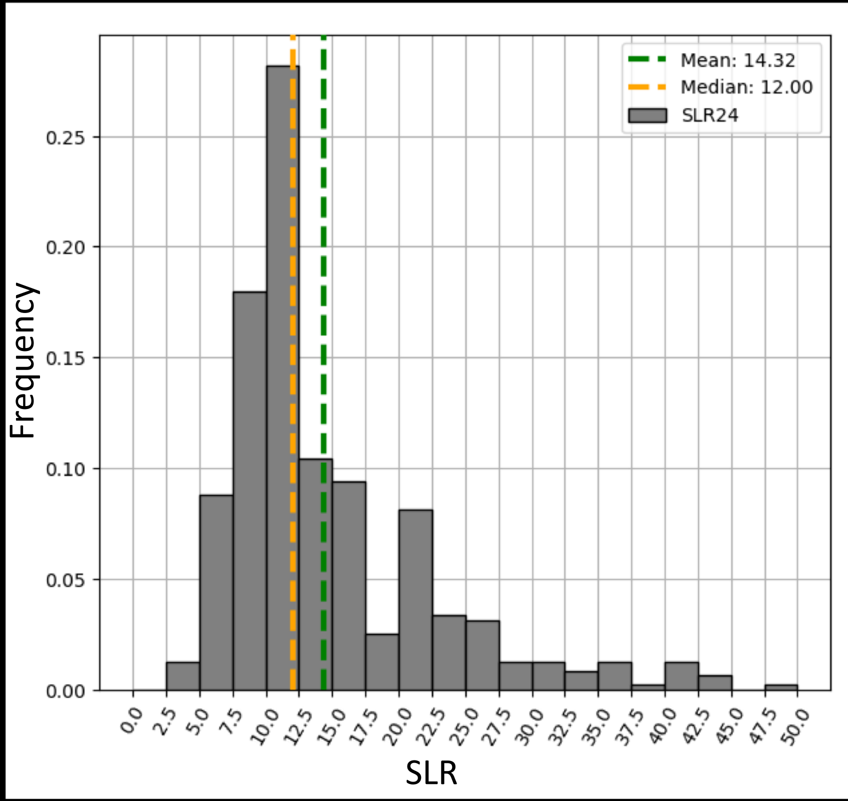


Climatological SLR from Baxter et al. (2005)

Sierra Nevada, CA



Northern Rockies, MT



Varies highly from maritime to continental ranges, with elevation, and with time

Solution

Train an algorithm on high-quality manual snowfall observations from around the Western US and eventually the entire US

Garbage in = Garbage out

We only use high-quality manual obs that properly weigh a core to obtain liquid equivalent. Gauges can miss >80% of storm total liquid in windy snowstorms.

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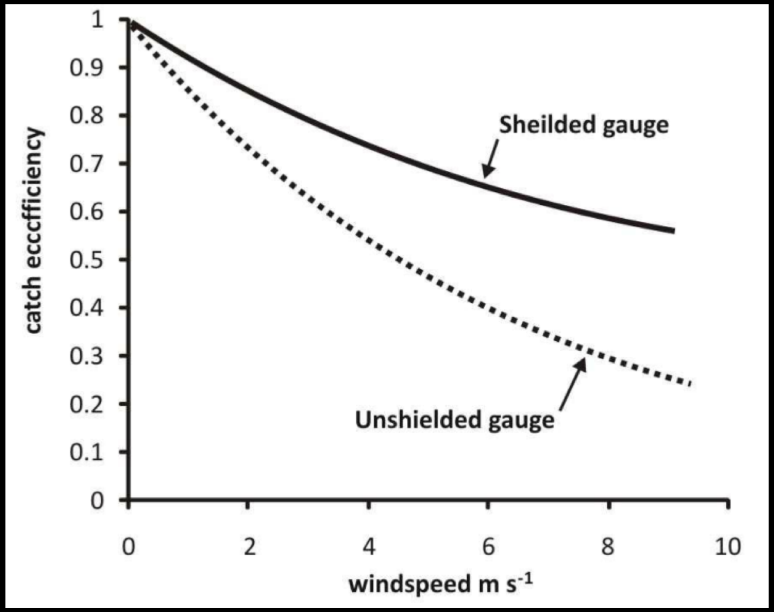
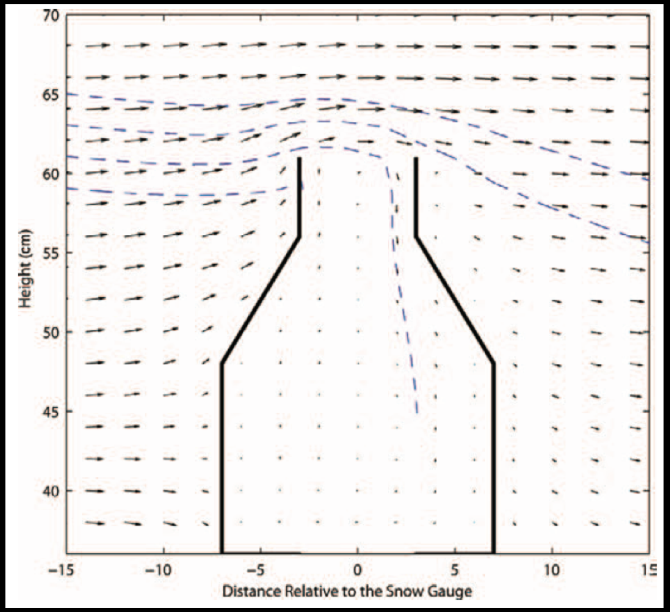
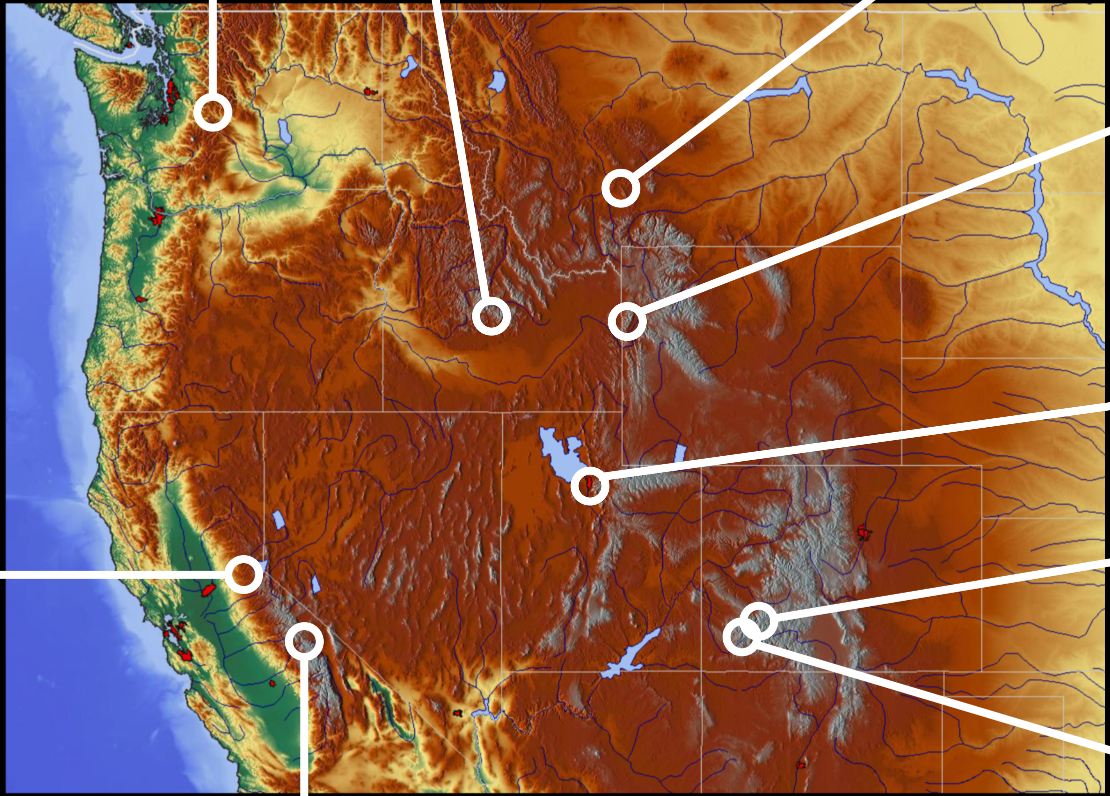


Macdonald and Pomeroy (2007)



Rasmussen et al. (2012)

SLR Datasets



Just acquired high quality manual obs from hundreds of the most discerning CoCoRaHS observers, for the full CONUS

Methodology

- QC data to remove events when the observed SWE disagrees significantly with nearby automated measurements, discard SLR<3 and SLR>40

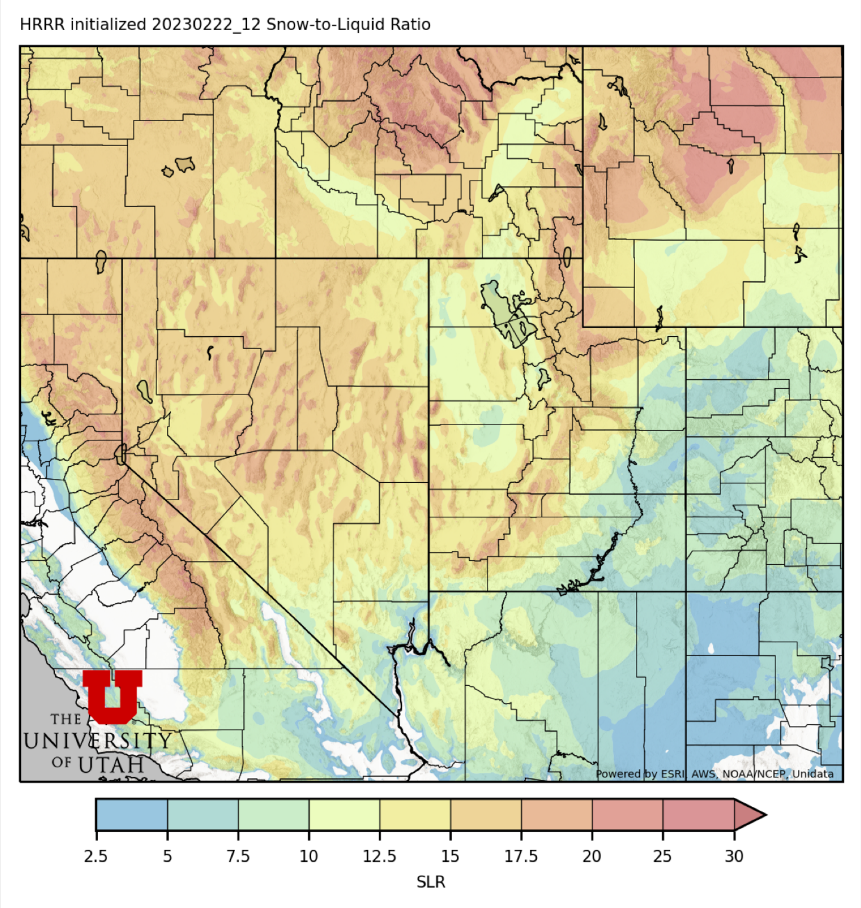
- Determine relationship between atmospheric variables and SLR
  - Temperature, wind speed, SWE amount**, cloud top temperature, specific humidity, solar angle, lapse rate
  - The training variables can be pulled from the ERA5 or the HRRR

- Use regression/machine learning to produce predictive algorithm for SLR that can be applied to variables in model forecasts

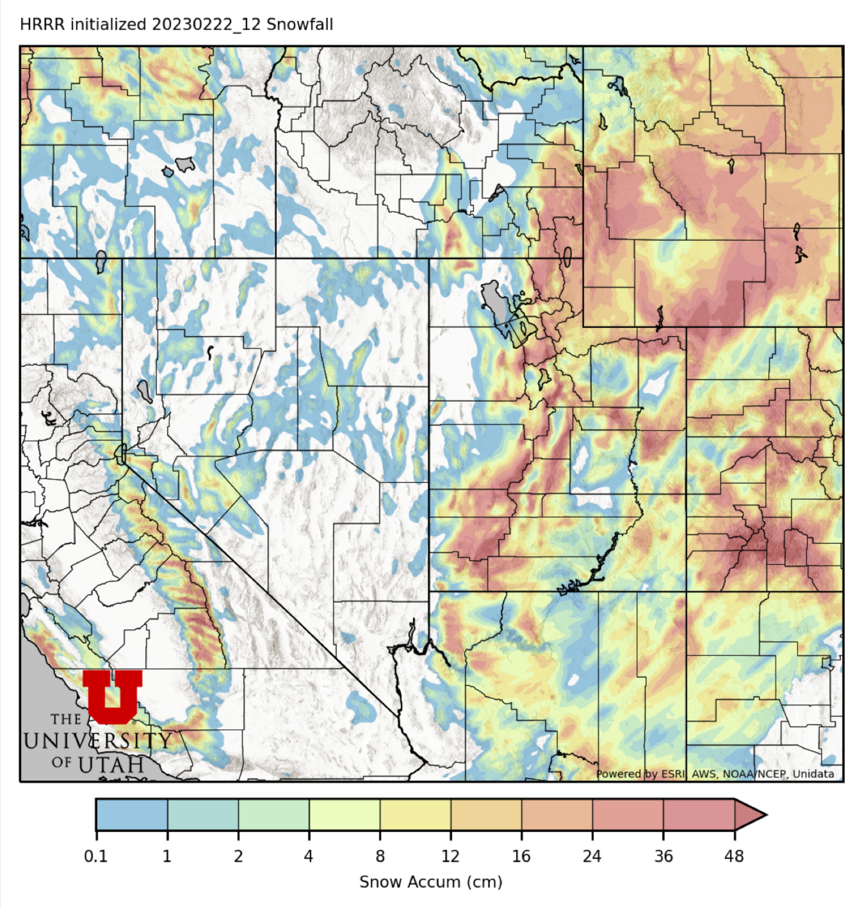
- Deal with the rain/snow line, and identify areas of sleet/freezing rain

HRRR

SLR

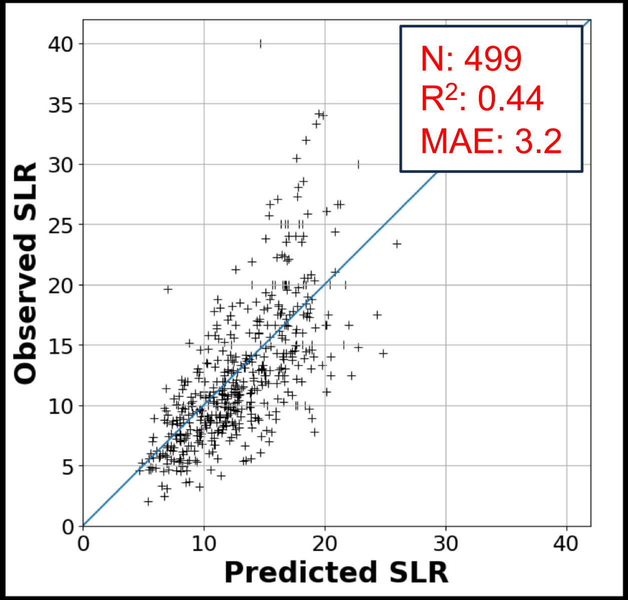


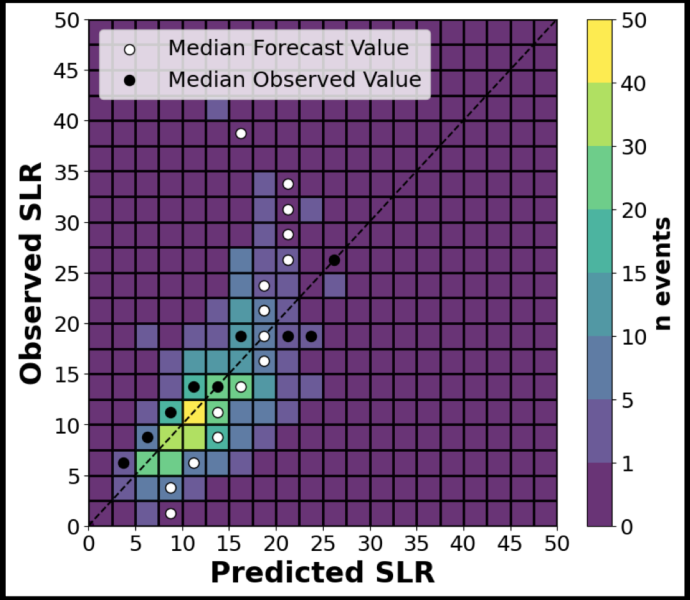
Snowfall

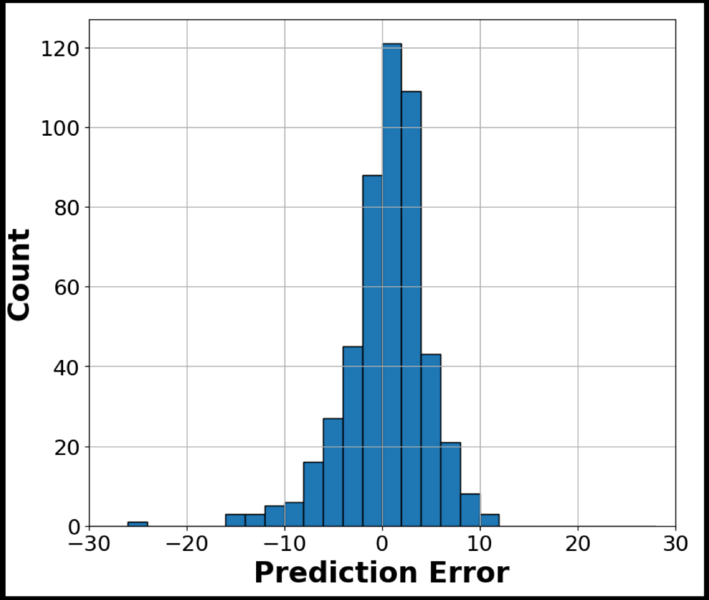


Available in realtime on weather.utah.edu

HRRR







Train on variables from HRRR for 2018-2023

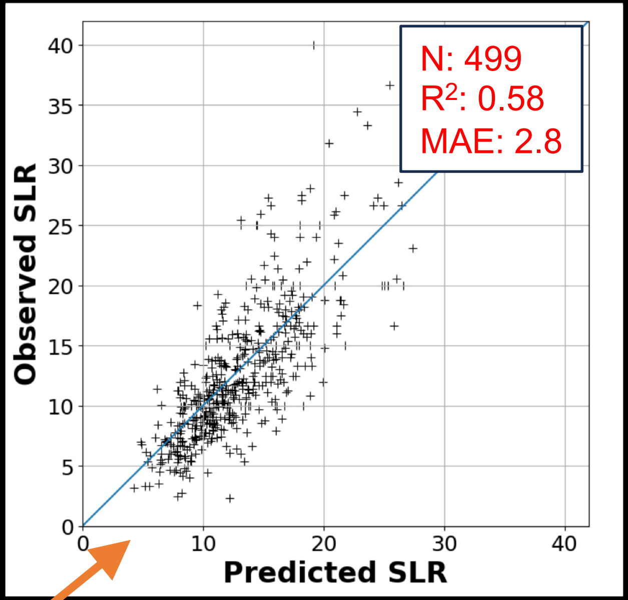
Temperature, wind speed, cloud top temperature, specific humidity, max solar angle, lapse rate at 6 vertical levels from 400 m to 2400 m AGL

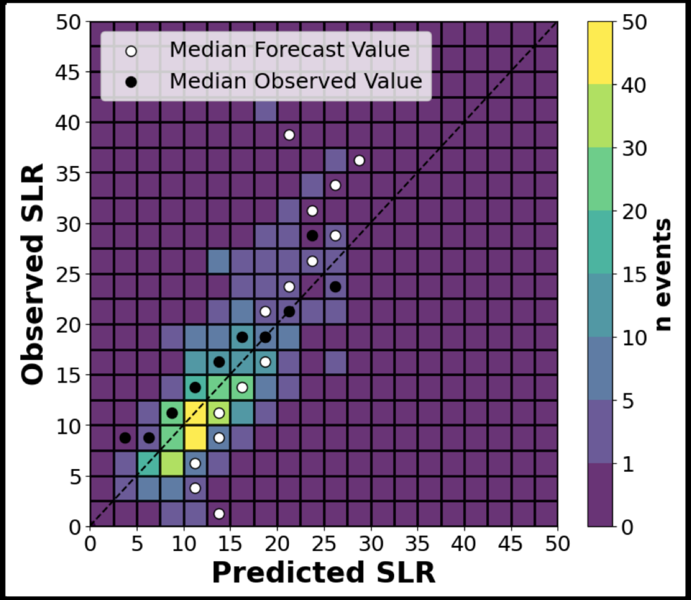
Random forest ML algorithm performs a bit better than linear regression, so will only show Random Forest results

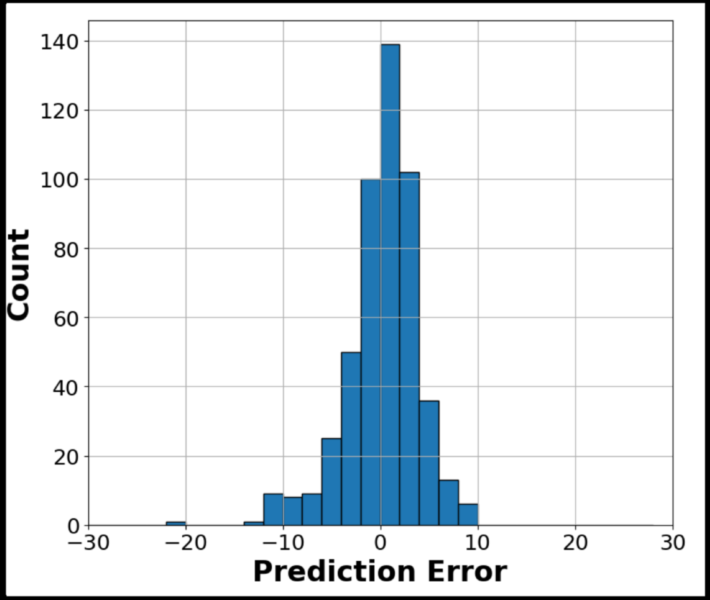
Randomly split data into 60% training, 40% testing – 499 testing obs shown here

SWE amount is tricky. The true SWE amount is hugely helpful, but models of course are far from the true SWE amount

HRRR



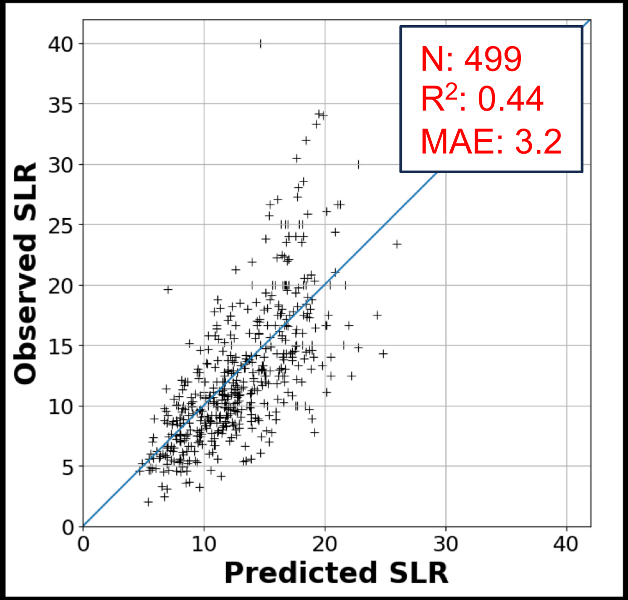




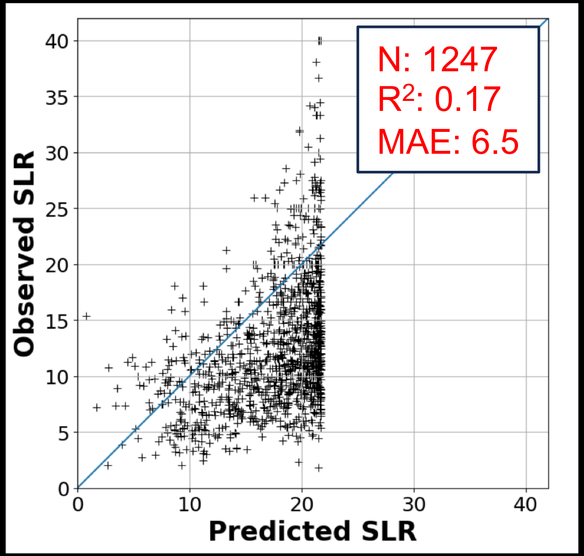
Using observed SWE as a predictor

SWE amount is tricky. The true SWE amount is hugely helpful, but models of course are far from the true SWE amount

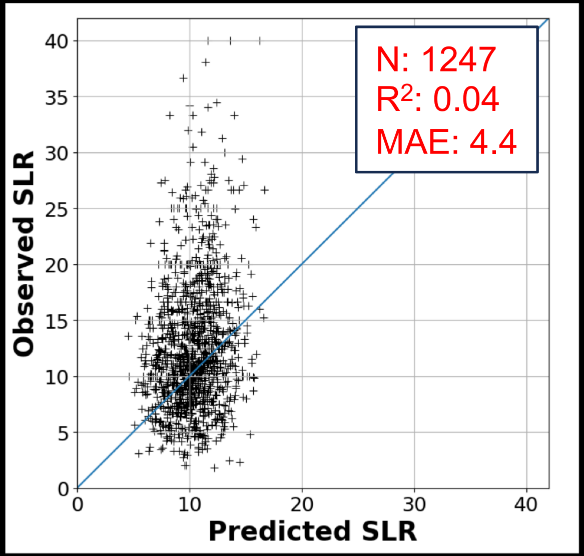
HRRR



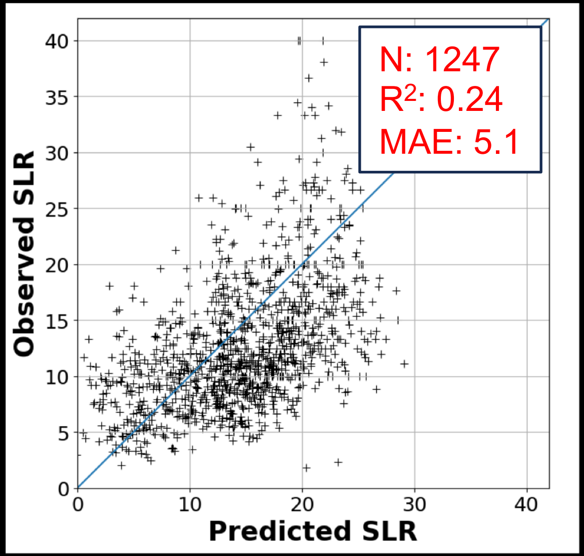
Currently used SLR methods:



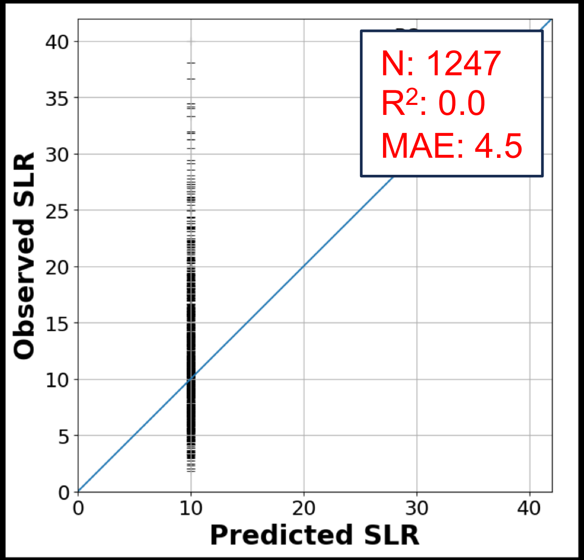
MaxTaloft



Cobb



Kuchera



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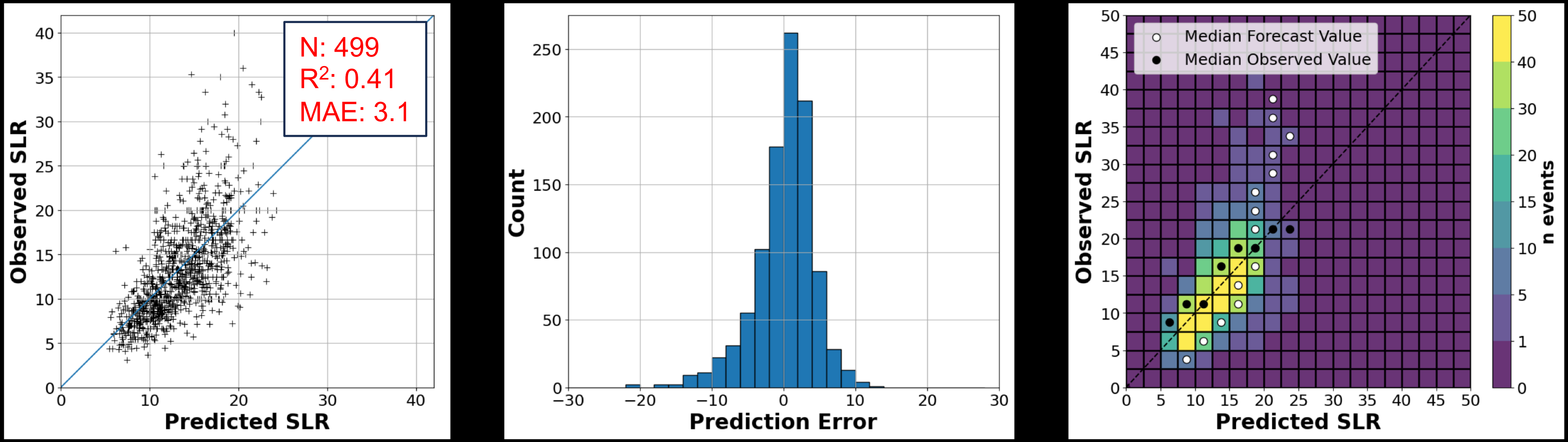
ERA5



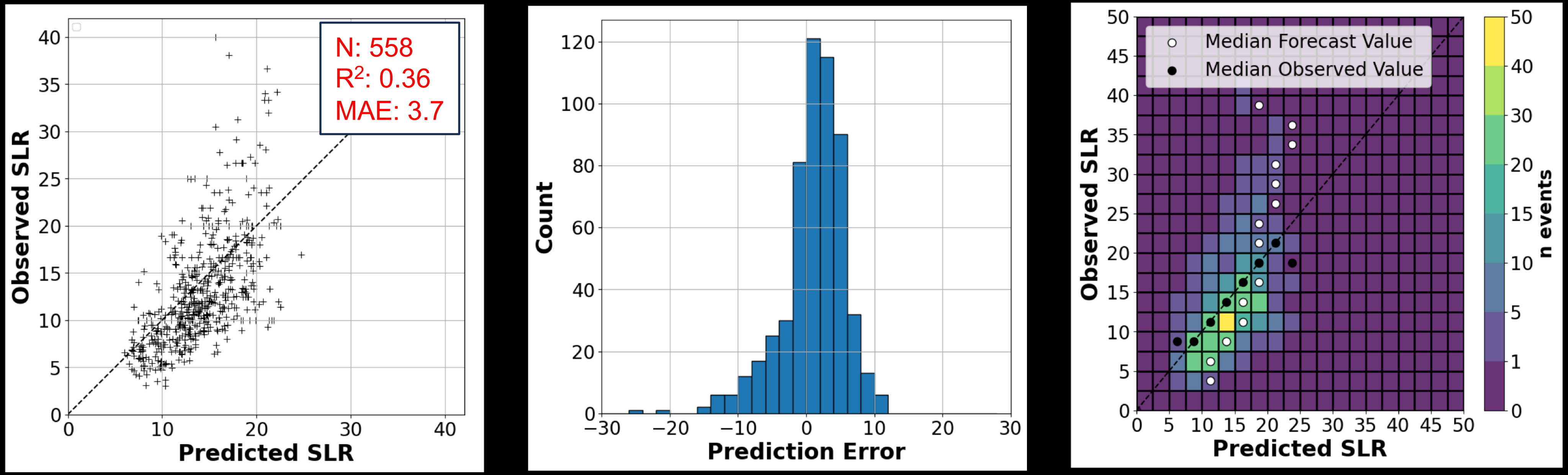
Can also train on reanalysis data for models without long archive periods, or models that undergo frequent large changes

Train on variables from ERA5 for 2006-2017. Again a random 60/40 train/test split is used

Note that the skill of the algorithm for ERA5 is comparable to the HRRR, despite the lower horizontal resolution of the ERA5

ERA5 has 137 vertical levels though, and is a reanalysis instead of a forecast.

GFS



Now apply the ERA5-trained algorithm to the 2018-2023 GFS forecasts

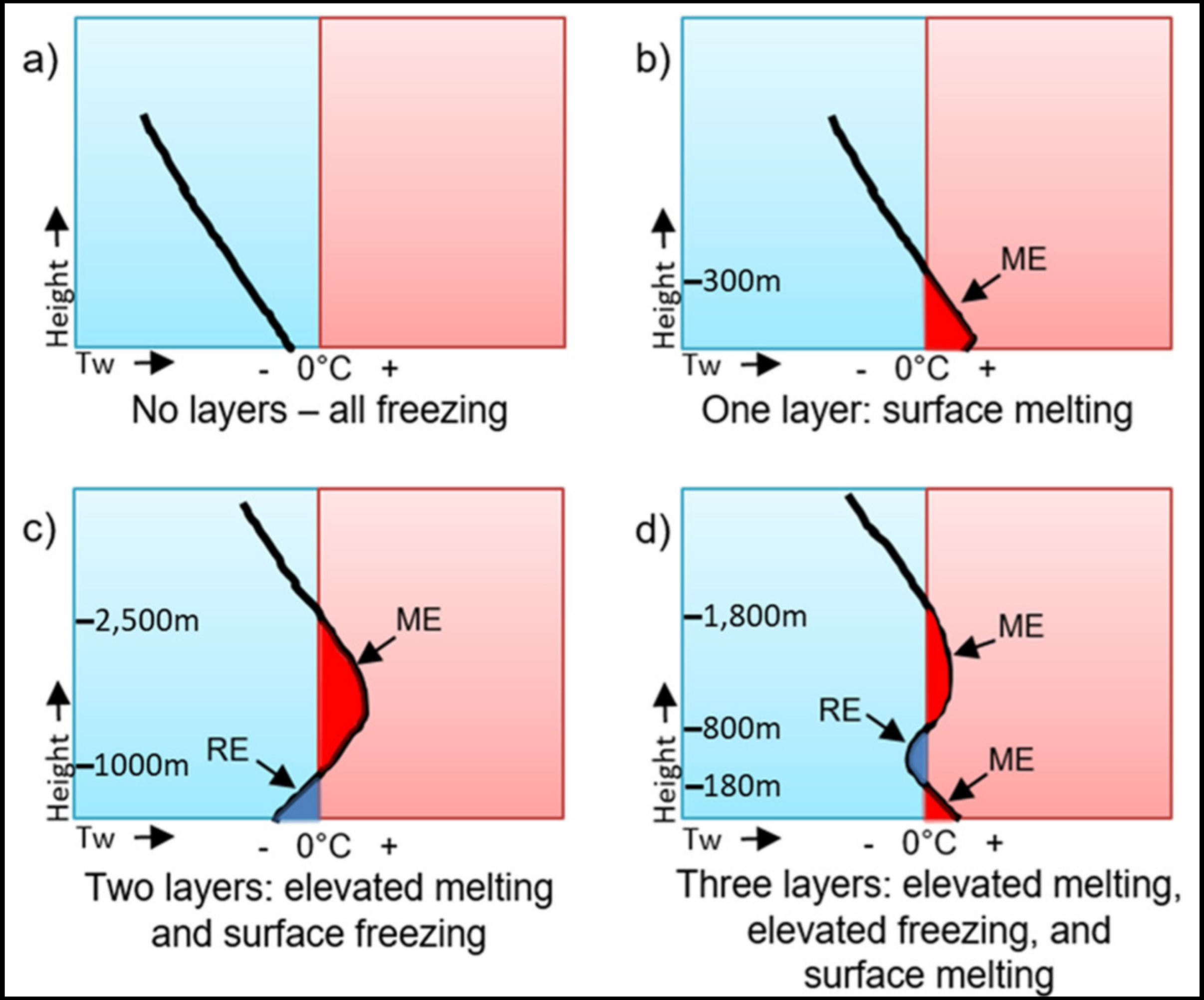
Performance is worse than the HRRR, but still significantly higher than currently-used SLR methods

Much lower vertical resolution than HRRR and ERA5. Much lower horizontal resolution than HRRR. Terrain is poorly represented in GFS

Rain/Snow Line and P-type

Working to implement a deterministic method based on Bourgouin (2000) to delineate snow, rain, sleet, and freezing rain

But also have the ability to implement a probabilistic method (Birk et al. 2021)



Birk et al. (2021)

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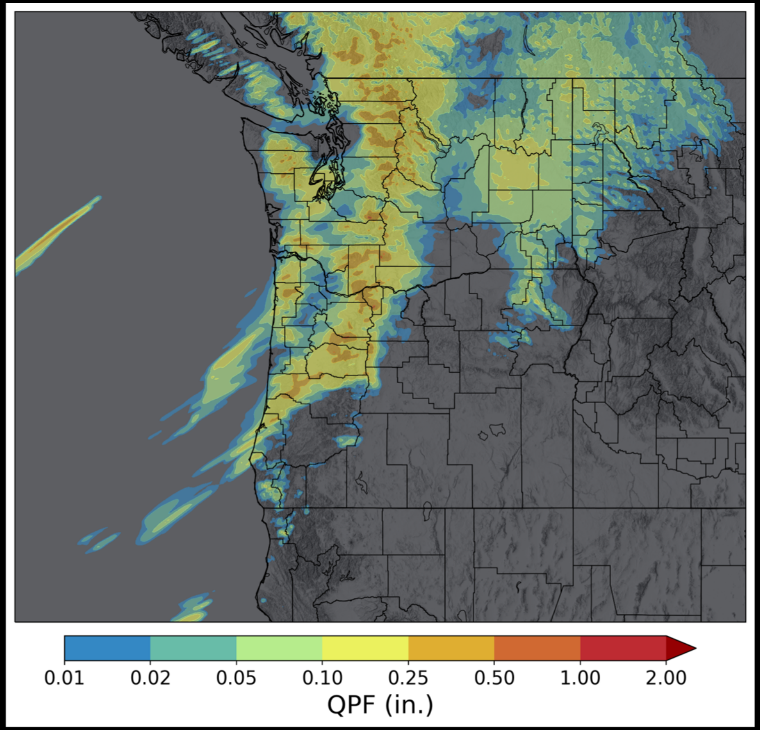

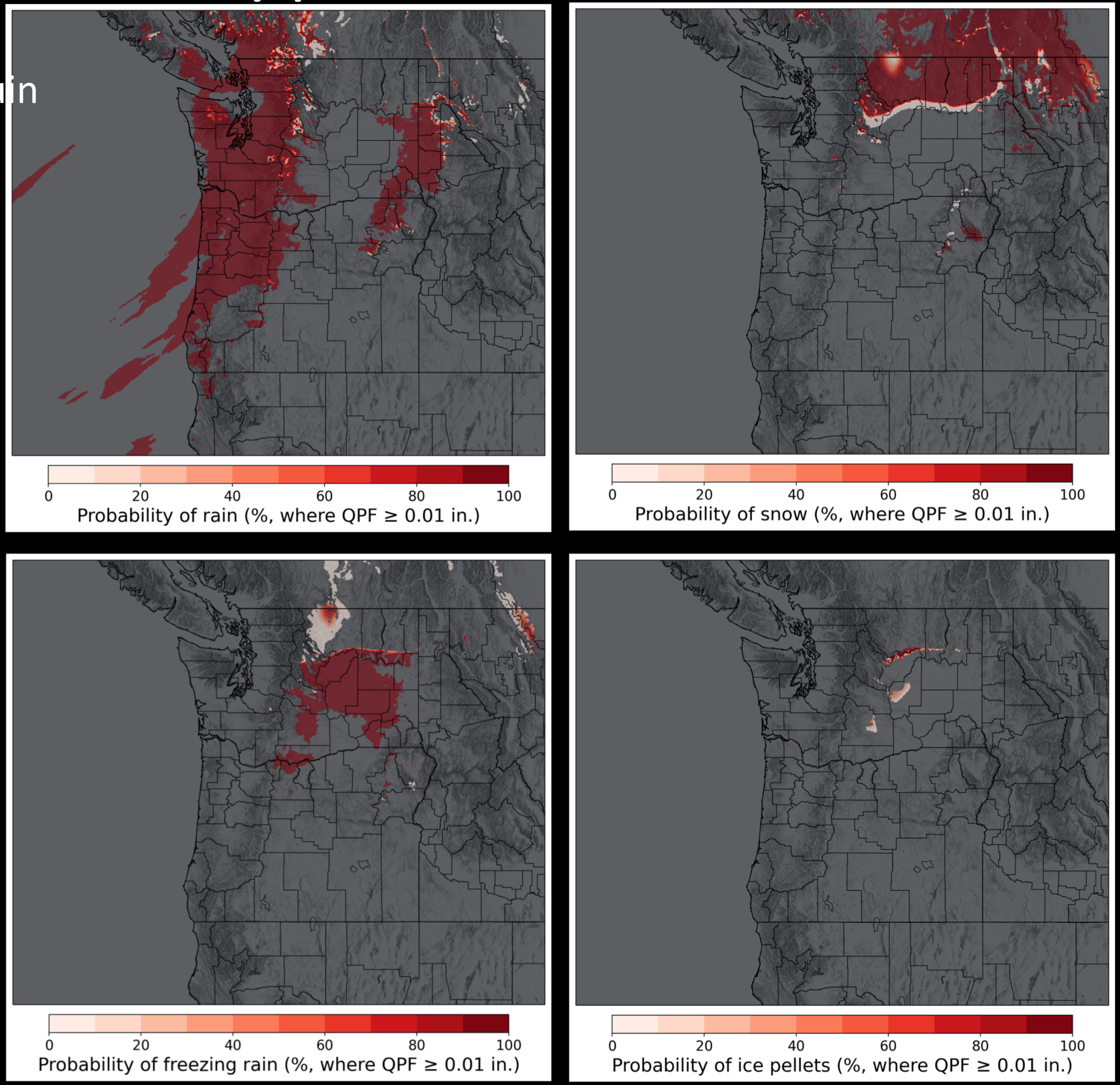

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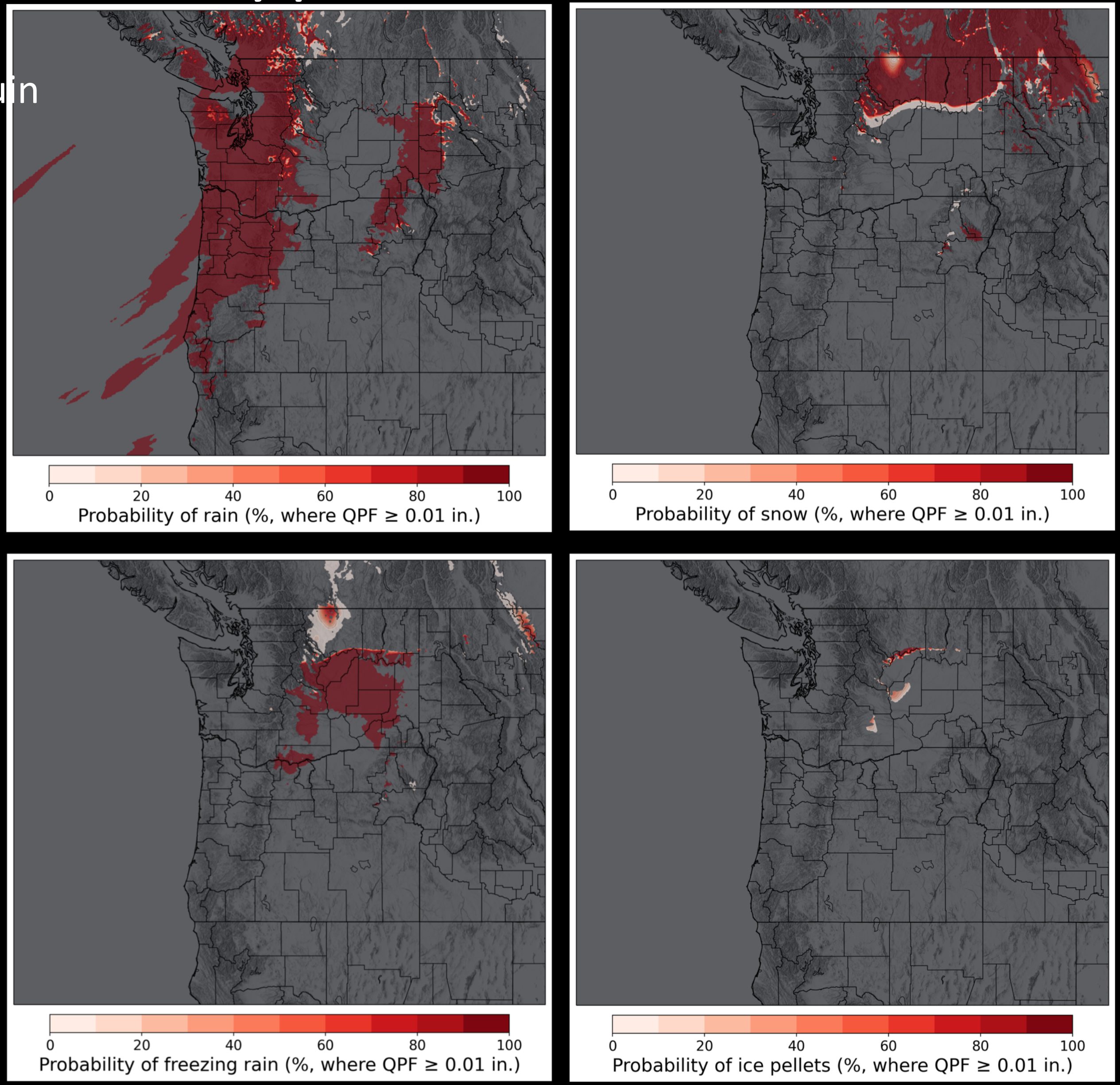
Experimented with the HRRR/RRFS P-type variables (cfrzr, cicep, frzr, etc) and did not find them to be skillful



Conclusions

Our system can be applied to anything from CAMs to global ensembles

Improves upon existing techniques for mountains of Western US by a sizeable margin

Will soon have an algorithm optimized for the CONUS, trained on hundreds of high-quality obs from CoCoRaHS

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