Improving Vertically Profiling Radar Bright Band Measurements to Support Snow Level Forecasts in the Western U.S.

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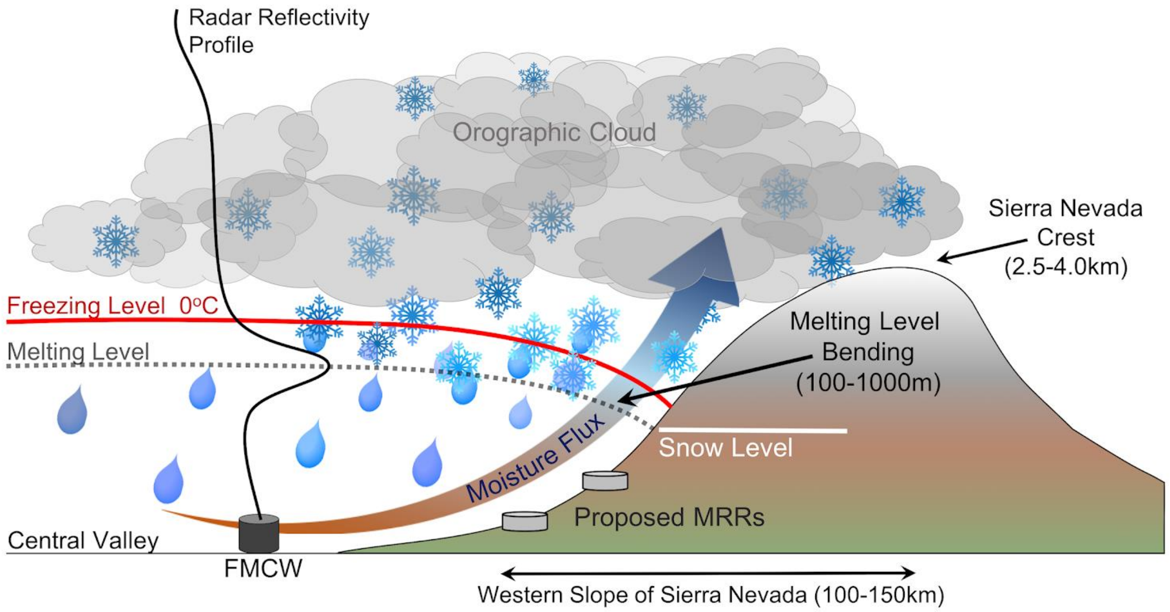
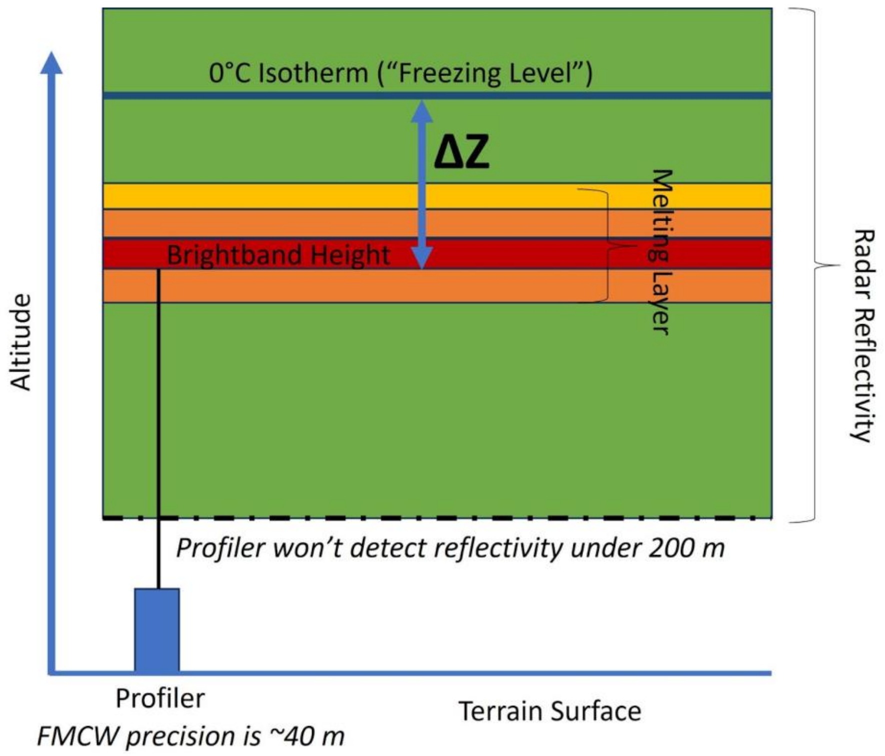
UC San Diego | SCRIPPS INSTITUTION OF OCEANOGRAPHY

SNOW LEVEL IS CRITICAL FOR FORECASTING RUNOFF

- **Snow level:** the elevation above which snow will fall, and below which precipitation falls as wet snow or rain with no accumulation
- Accurate knowledge of snow level influences ability to forecast the timing and magnitude of runoff generation





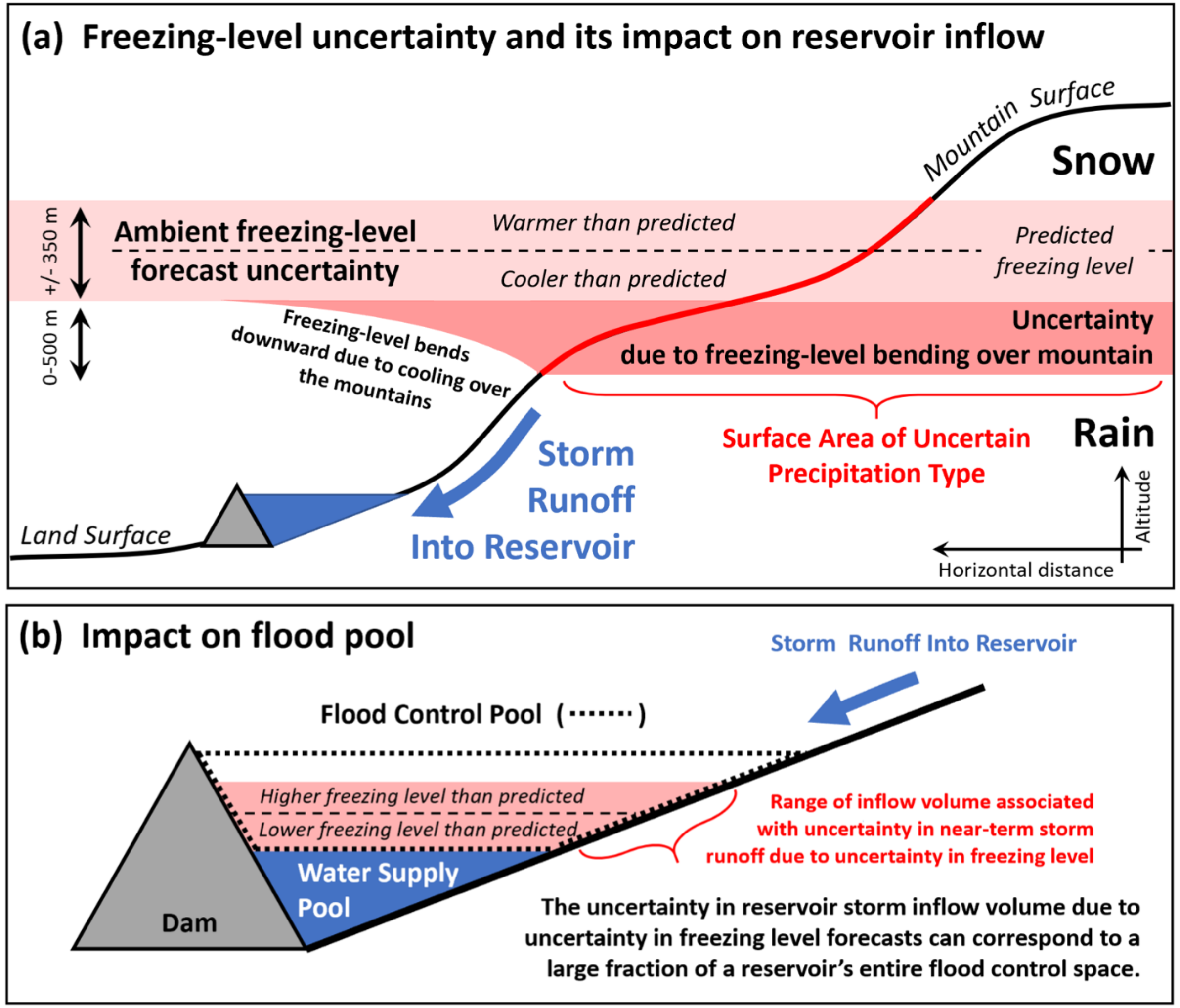
Left: figure illustrating freezing level, melting level, and snow level

Right: diagram of altitude vs. reflectivity depicting the freezing level, melting layer, and bright band height

BETTER FREEZING LEVEL FORECASTS NEEDED FOR RESERVOIR OPERATIONS

Case study from Lake Oroville and New Bullards Bar Reservoirs in California

- A freezing level forecast error of 350 m is equivalent to a runoff volume uncertainty up to over a half of the reservoir flood pool storage
- The uncertainties can increase by up to >3% for each additional inch of precipitation
- *"This paper is intended to highlight the impact of Z_{FL} forecast error and the **critical need of Z_{FL} forecast accuracy** for reservoir operations"*



Sumargo, E., F. Cannon, F. M. Ralph, and B. Henn, 2020. Freezing level forecast error can consume reservoir flood control storage: Potentials for Lake Oroville and New Bullards Bar reservoirs in California. Water Resources Research, 56.

OUR GOAL: IMPROVE FREQUENCY & ACCURACY OF MRR SNOW LEVEL

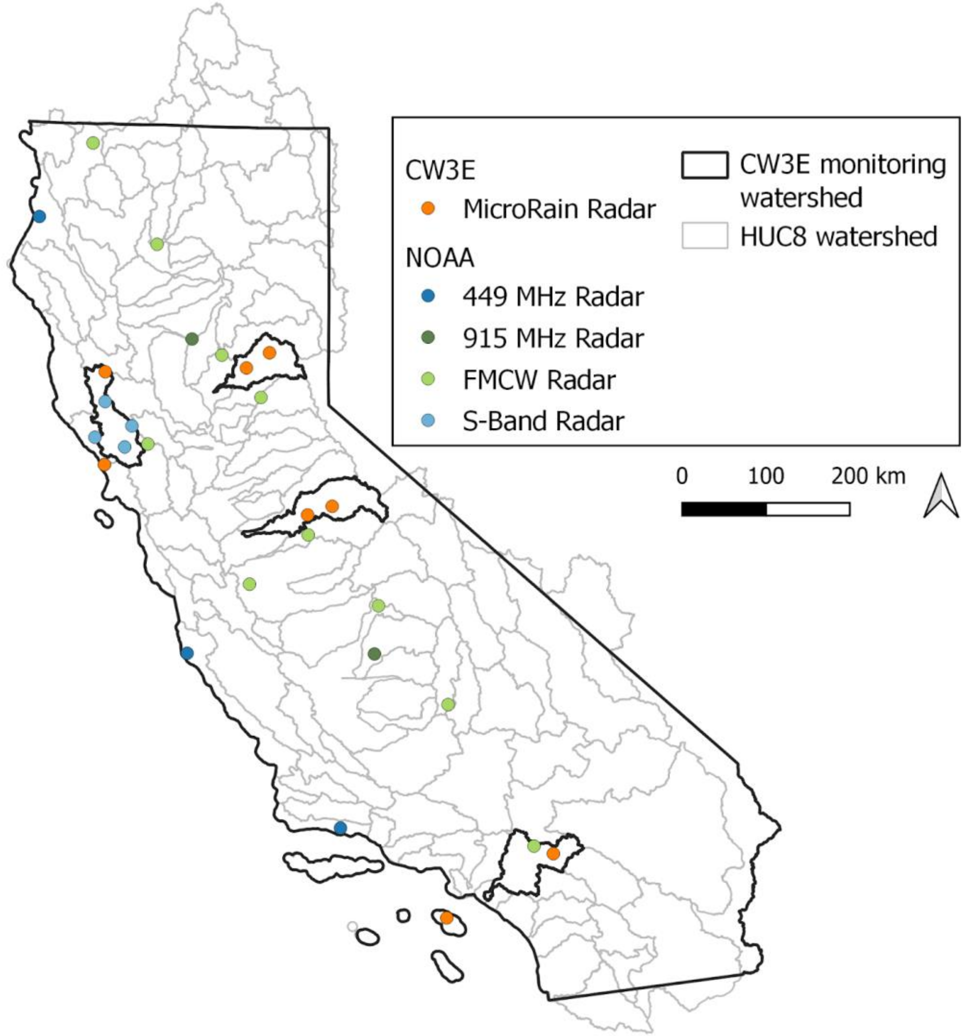
CW3E MRR network

- CW3E has deployed a network of 10 Micro Rain Radars (MRR2s) across the western U.S.
- We use an algorithm based on White et al. 2003 to detect hourly radar bright band height values as a proxy for snow level

Research goals

- Can we quantify the performance of our existing MRR algorithm at deriving accurate and frequent snow level measurements?
- Can we improve the accuracy and frequency of these measurements?

Answer: Yes (with some limitations)



Map of CW3E and NOAA radars in California

MRR IS A LOW-COST, PORTABLE INSTRUMENT FOR OBSERVING SNOW LEVEL

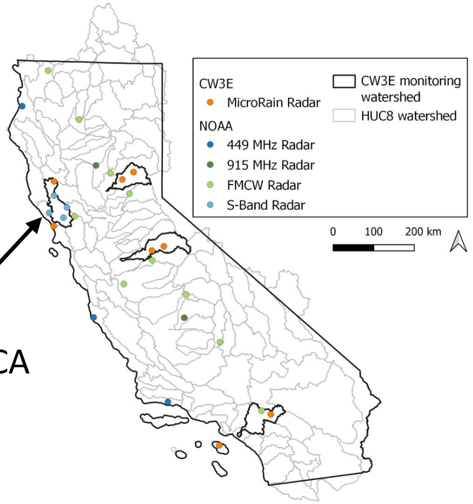
NOAA SPROF (S-band)
10km range, 63m resolution

NOAA FMCW (S-band)
10km range, 40m resolution

CW3E MRR (K-band)
3km range, 100m resolution

Dataset used in this study

- Co-located MRR and SPROF at Cazadero, CA from Dec 2014 to Mar 2015
- MRR data (200m resolution) provided by authors of Massman et al. 2017
- SPROF data obtained from NOAA Physical Sciences Laboratory

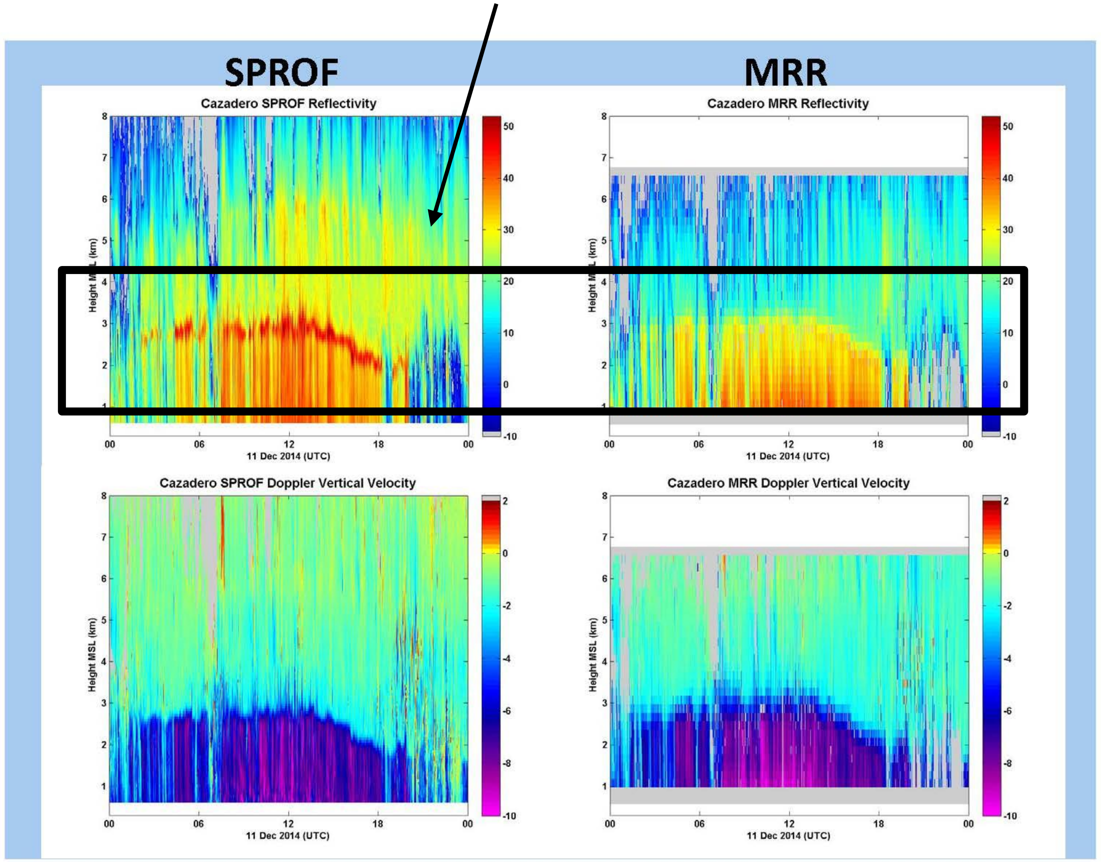


Cazadero, CA

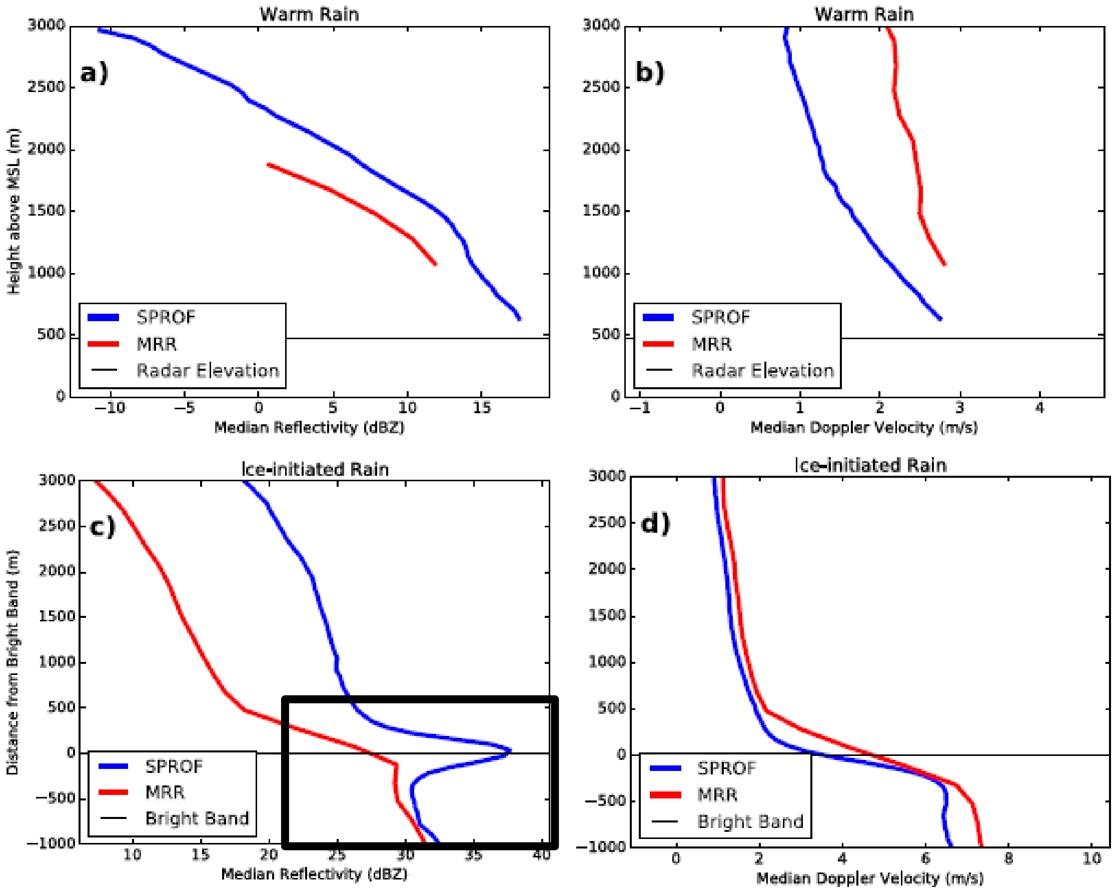
Massmann, A. K., Minder, J. R., Garreaud, R. D., Kingsmill, D. E., Valenzuela, R. A., Montecinos, A., ... & Snider, J. R. (2017). The Chilean Coastal Orographic Precipitation Experiment: Observing the influence of microphysical rain regimes on coastal orographic precipitation. *Journal of Hydrometeorology*, *18*(10), 2723-2743.

MRR HAS LOWER REFLECTIVITY SENSITIVITY VS. SPROF

SPROF shows pronounced peak in reflectivity (radar bright band) while MRR does not



SPROF vs. MRR reflectivity and vertical velocity on Dec 11, 2014



SPROF vs. MRR median profiles of reflectivity and vertical velocity

Left: provided by Justin Minder, University at Albany; right: from Massman et al. 2017

EXISTING ALGORITHM: DETECTION RATE OF 33%, ACCURACY OF 85%

Define performance metrics:

- **Probability of detection (POD):** how often does the algorithm correctly detect that a bright band height value is present?
- **Success ratio (SR):** when the algorithm detects a bright band height value, how often is it correct (within tolerance of +/-100m)?

Existing MRR algorithm: POD=33%, SR=85% (n=164)

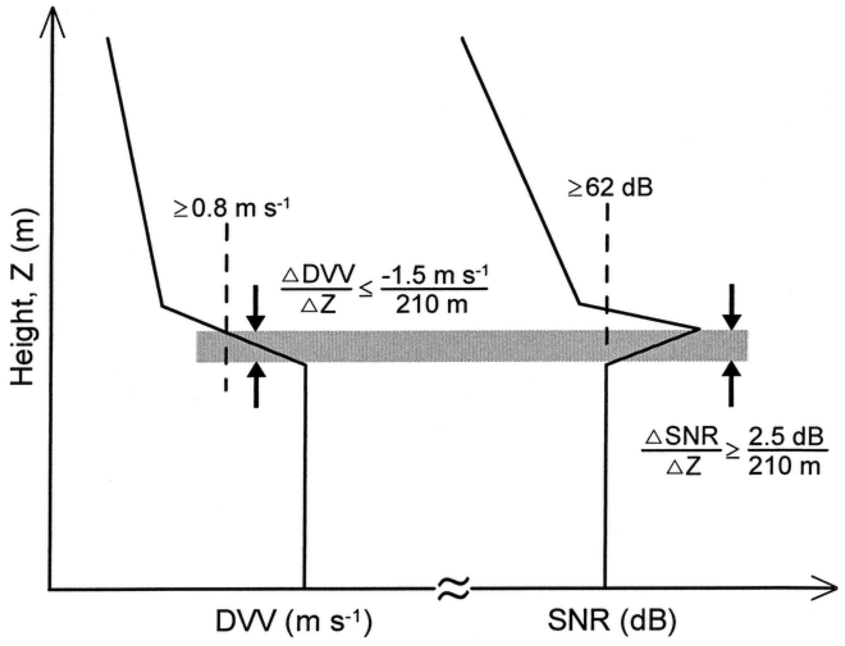


Diagram showing how the White et al. 2003 algorithm works

$$POD = \frac{hits}{hits + misses} \qquad SR = \frac{hits}{hits + false\ alarms}$$

Pfaff, T., Engelbrecht, A., & Seidel, J. (2014). Detection of the bright band with a vertically pointing k-band radar. http://dx.doi.org/10.18419/opus-599

White, A. B., P. J. Neiman, F. Ralph, D. Kingsmill, and P. Persson, 2003: Coastal orographic rainfall processes observed by radar during the California land-falling jets experiment. J. Hydrometeor., 4, 264–282, doi:10.1175/1525-7541(2003)4,264: CORPOB.2.0.CO;2.

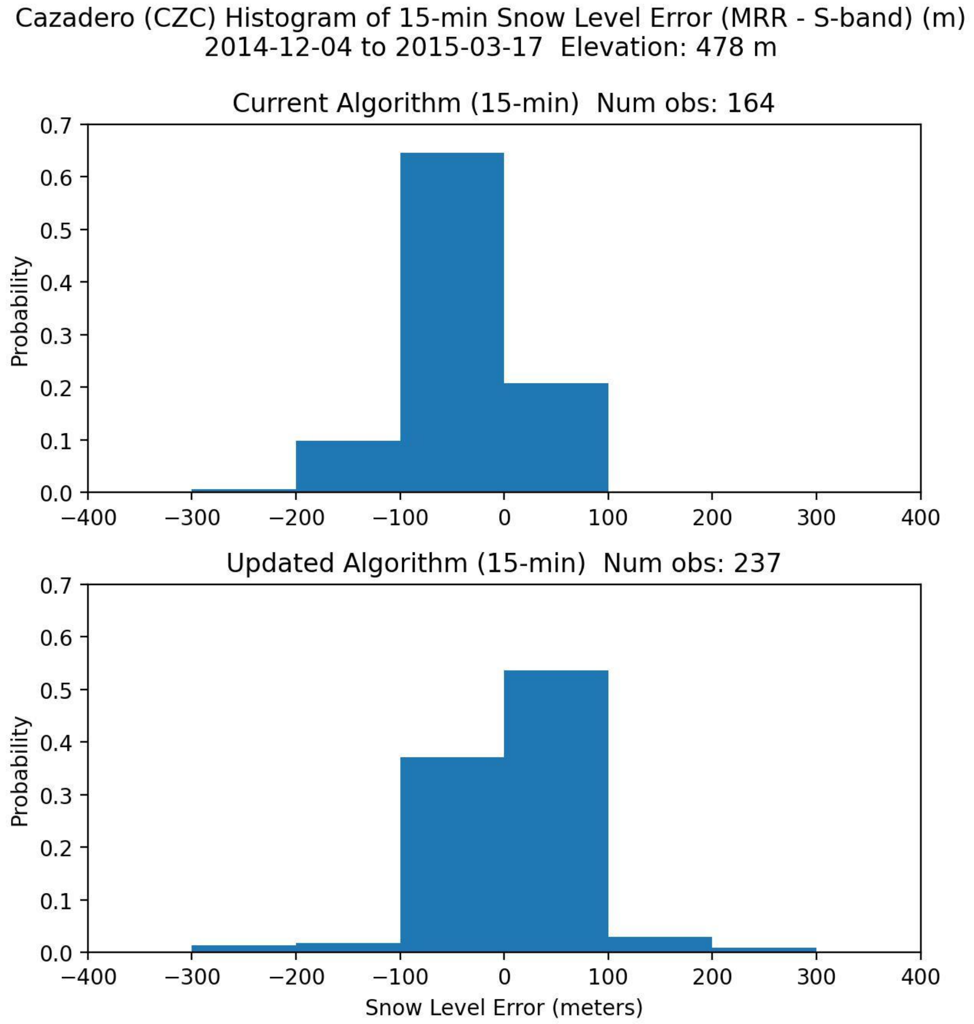
IMPROVED ALGORITHM IMPROVES BOTH FREQUENCY & ACCURACY

Improvements:

- **Adjusted the reflectivity gradient threshold** to compensate for the lower sensitivity of the MRR
- **Added QC checks** to remove erroneously high or low values
- **Increased resolution to 15-min**, matching format of NOAA profilers and making comparisons easier

Existing algorithm: POD=33%, SR=85% (n=164)

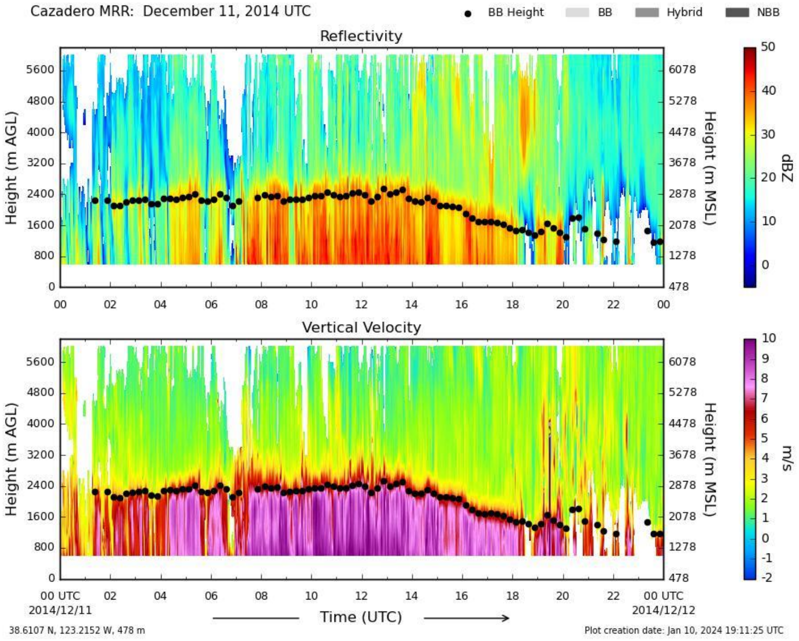
Improved algorithm: POD=50%, SR=91% (n=237)



IMPROVED ALGORITHM MORE CLOSELY MATCHES SPROF SNOW LEVEL

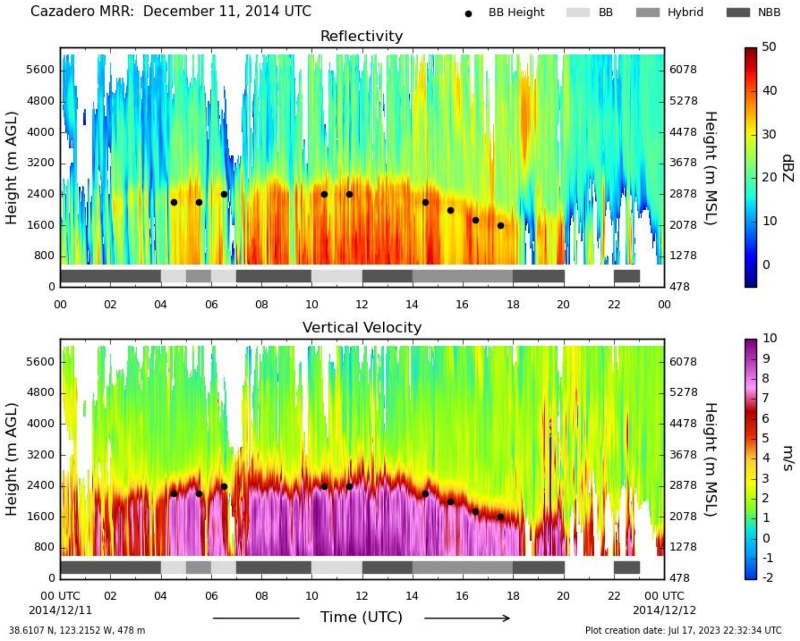
Example day: Dec 11, 2014

SPROF



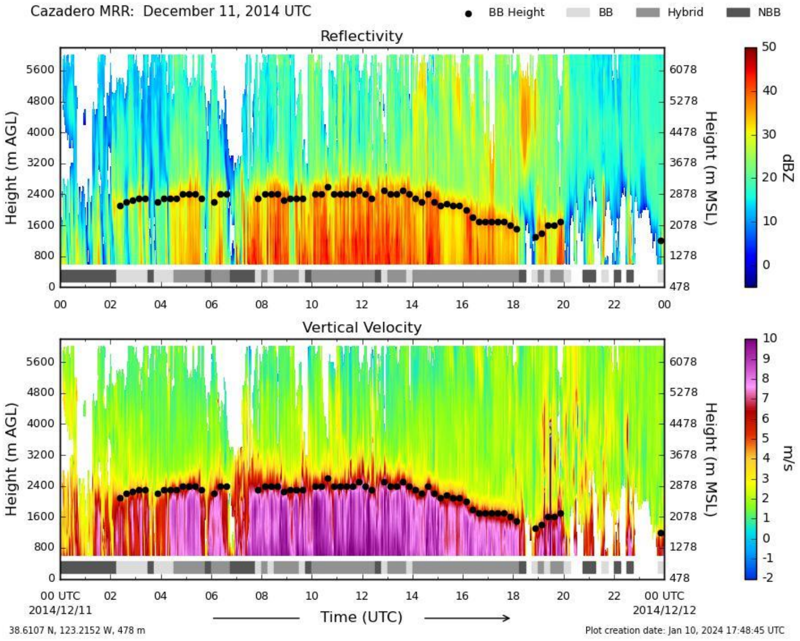
SPROF snow level overlaid on MRR reflectivity/vertical velocity

Existing MRR algorithm



Existing (hourly) MRR bright band algorithm

Improved MRR algorithm



Improved (15-min) MRR bright band algorithm with adjusted thresholds and QC steps

IMPROVED ALGORITHM WAS SELECTED FROM MANY TESTED METHODS

	Algorithm	POD [%]	SR [%]
1	**Existing algorithm: search for heights meeting Ze and W gradient thresholds**	**32.86**	**85.37**
2	Existing algorithm modified to search for peak Ze value within 600m above identified heights	31.9	81.71
3	Lin 2019: classify rain vs. snow based on vertical velocity	12.06	20.43
4	Existing algorithm modified with Ze threshold to 0	44.91	91.08
5	Existing algorithm modified with Ze threshold to 0 and resampling threshold to 25%	67.25	79.01
6	Existing algorithm modified with Ze threshold to 0 and fixing NaN issue	44.44	91
7	Existing algorithm modified with Ze threshold to 0, fixing NaN issue, and resampling threshold set to 33%	56.37	88.19
8	Existing algorithm modified with Ze threshold to 0, fixing NaN issue, and QC steps	44.11	91.39
9	Existing algorithm modified with Ze threshold to 0, W threshold set to 0, fixing NaN issue, and QC steps	56.25	6.95
10	Existing algorithm modified with Ze threshold to 0, W threshold set to -0.0045, fixing NaN issue, and QC steps	53.77	88.37
11	Existing algorithm modified with Ze threshold to 0, W threshold set to -0.005, fixing NaN issue, and QC steps	50.59	89.63
12	**Final algorithm: Existing algorithm modified with Ze threshold to -0.00476, fixing NaN issue, and QC steps**	**50.12**	**90.72**

Lin, D., Pickering, B., & Neely III, R. R. (2020). Relating the radar bright band and its strength to surface rainfall rate using an automated approach. *Journal of Hydrometeorology*, *21*(2), 335-353. https://doi.org/10.1175/JHM-D-19-0085.1

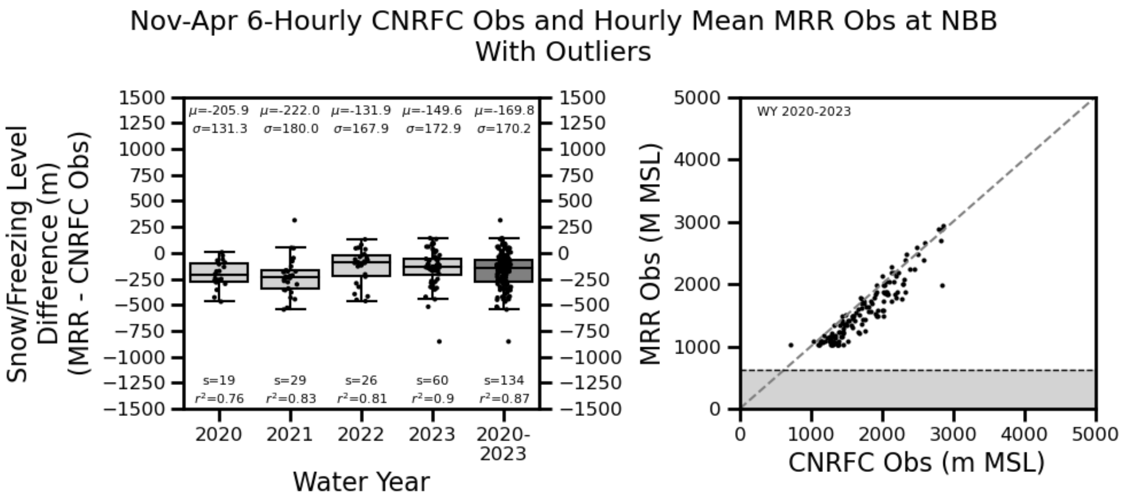
ACCURATE OBSERVATIONS ARE CRITICAL FOR FORECAST VERIFICATION

Using the data for forecast verification

- Verifying freezing level from a hi-res model output near a given site location over a given period (e.g., CZC during WY2023-2024)
- Performance metrics remain similar when resampled to model time steps
  - 15-min resolution: POD=50%, SR=91% (n=237)
  - 1-hour resolution: POD=47%, SR=87% (n=73)
  - 3-hour resolution: POD=47%, SR=92% (n=25)
  - 6-hour resolution: POD=50%, SR=92% (n=13)

Resampled observations are the median of values within +/-15 min of each model time step

Snow level vs. freezing level



CNRFC Obs: nearest grid point from 6-hourly 4km gridded freezing level product.
Cases with large hourly variations in 0°C were removed.

LIMITATIONS & NEXT STEPS

Limitations of study

- Small sample size (3 months of data, from Dec 2014 – Mar 2015)
- Single location
- Differing vertical resolutions: the MRR in this study set to 200m; our CW3E radars use 100m

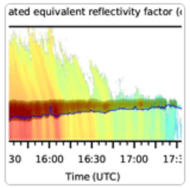
Next steps

- We recommend co-locating MRRs with other NOAA SPROF and FMCW radars across the western U.S.
- Improve QC for rapid snow level changes
- Reprocess all CW3E MRR snow level data
- Explore other algorithms, such as machine learning methods

Research article | 09 Dec 2020

Detecting the melting layer with a micro rain radar using a neural network approach

Maren Brast and Piet Markmann



Brast, M. and Markmann, P.: Detecting the melting layer with a micro rain radar using a neural network approach, Atmos. Meas. Tech., 13, 6645–6656, https://doi.org/10.5194/amt-13-6645-2020, 2020.

SUMMARY & DATA ACCESS

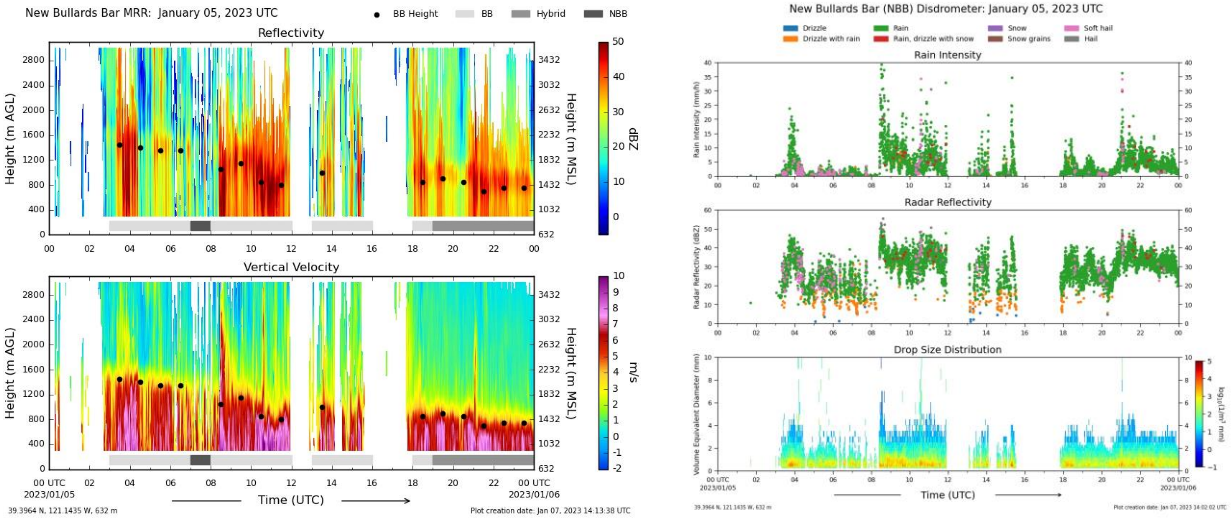
Key findings

- We improved our MRR snow level measurements to a detection rate of 50% and accuracy of 91% (within +/-100m) compared to the NOAA SPROF
- Demonstrated utility of the MRR for snow level observations despite its limited reflectivity sensitivity

Data access

- Data available on CW3E website
- California sites available on California Data Exchange (CDEC)

Contact: Peter Yao (peyao@ucsd.edu)



Example plots from CW3E website: MRR (left), disdrometer (right)

CW3E website

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