Center for Western Weather and Water Extremes

Quantifying Skill in Forecasting Rain-Snow Levels in Atmospheric River Storms in California Across Models

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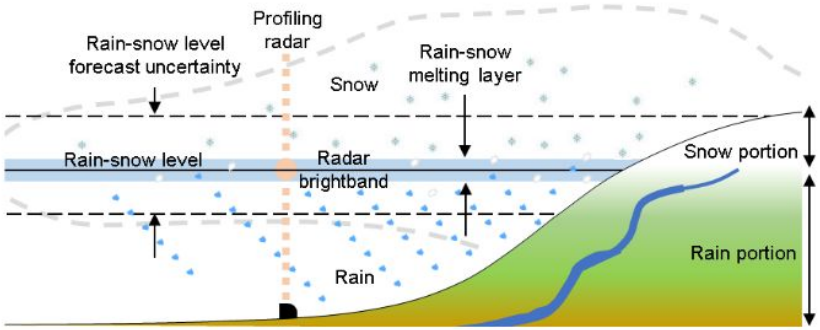
IARC 2018, Scripps Forum, La Jolla June 27, 2018

UC San Diego

Overview

Uncertainty in AR rain-snow level forecasts is a key driver of streamflow prediction errors in rain-snow transition watersheds (i.e., Sierra Nevada)



Goals:

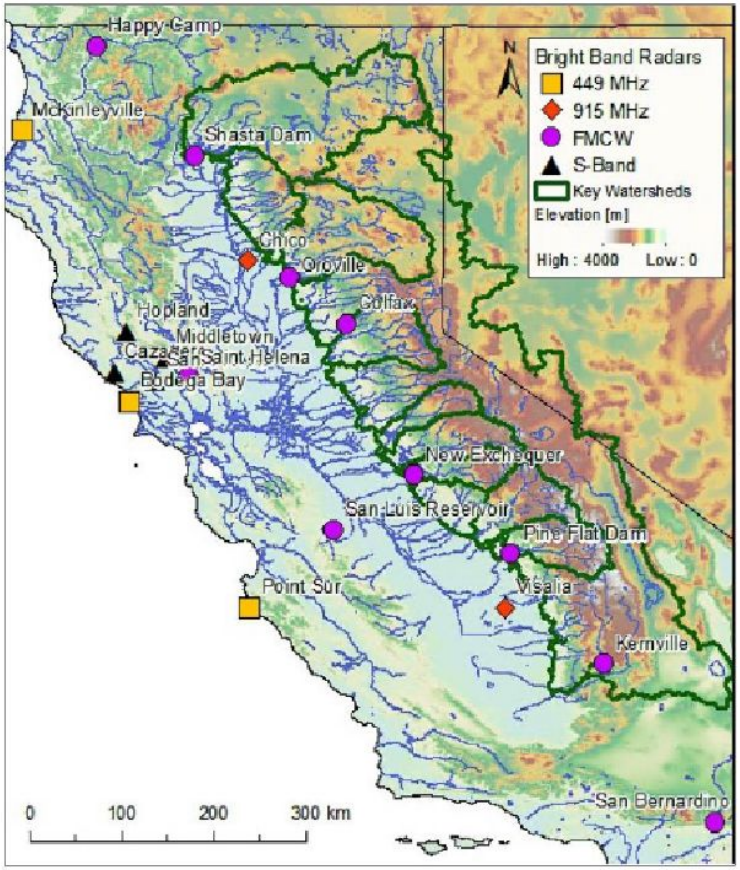
- Assess skill in West-WRF[1], CNRFC operational, and GEFS rain-snow level by verification against observed radar brightband heights across CA
- See how skill varies with respect to observed precipitation rates and rain-snow levels

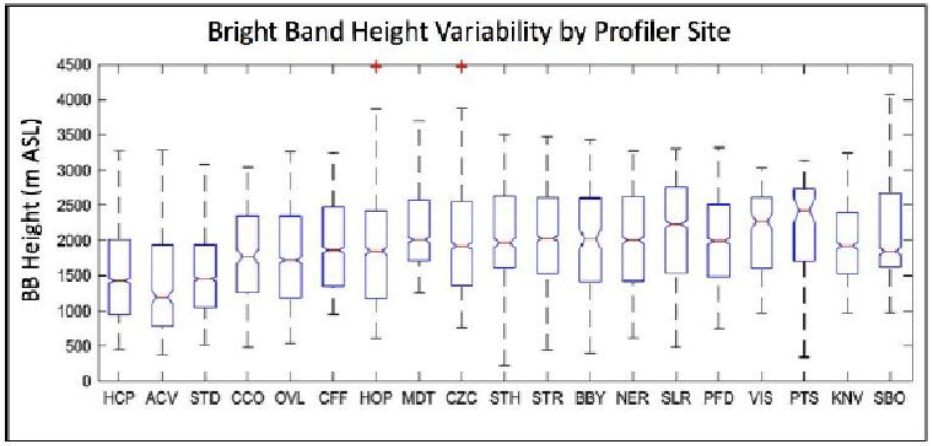
[1]Martin, A., and coauthors, 2018. *J. Hydromet, early release*.

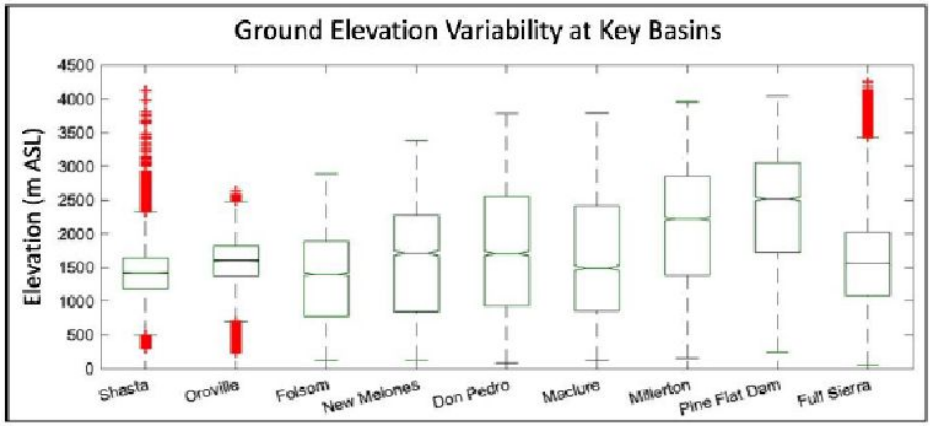
Data

- Observations
  - 19 CA profiling radars' (FMCWs, 915 and 449 MHz, S-band) brightbands over WY 2017
  - CNRFC QPE grids
  - Topographic distributions (hypsometry) of key watersheds
- Model forecasts of rain-snow level:
  - CW3E's West-WRF 3 km forecasts, initialized 1-2 times daily Dec – March 2016-2017
  - CNRFC archived Z0C operational forecast grids at 4 km, derived from GFS and other model guidance
  - GEFS reforecast version 2 (GEFSRv2) ensemble, 0.5 degree, daily; Z0C interpolated from temperature on eta and pressure levels

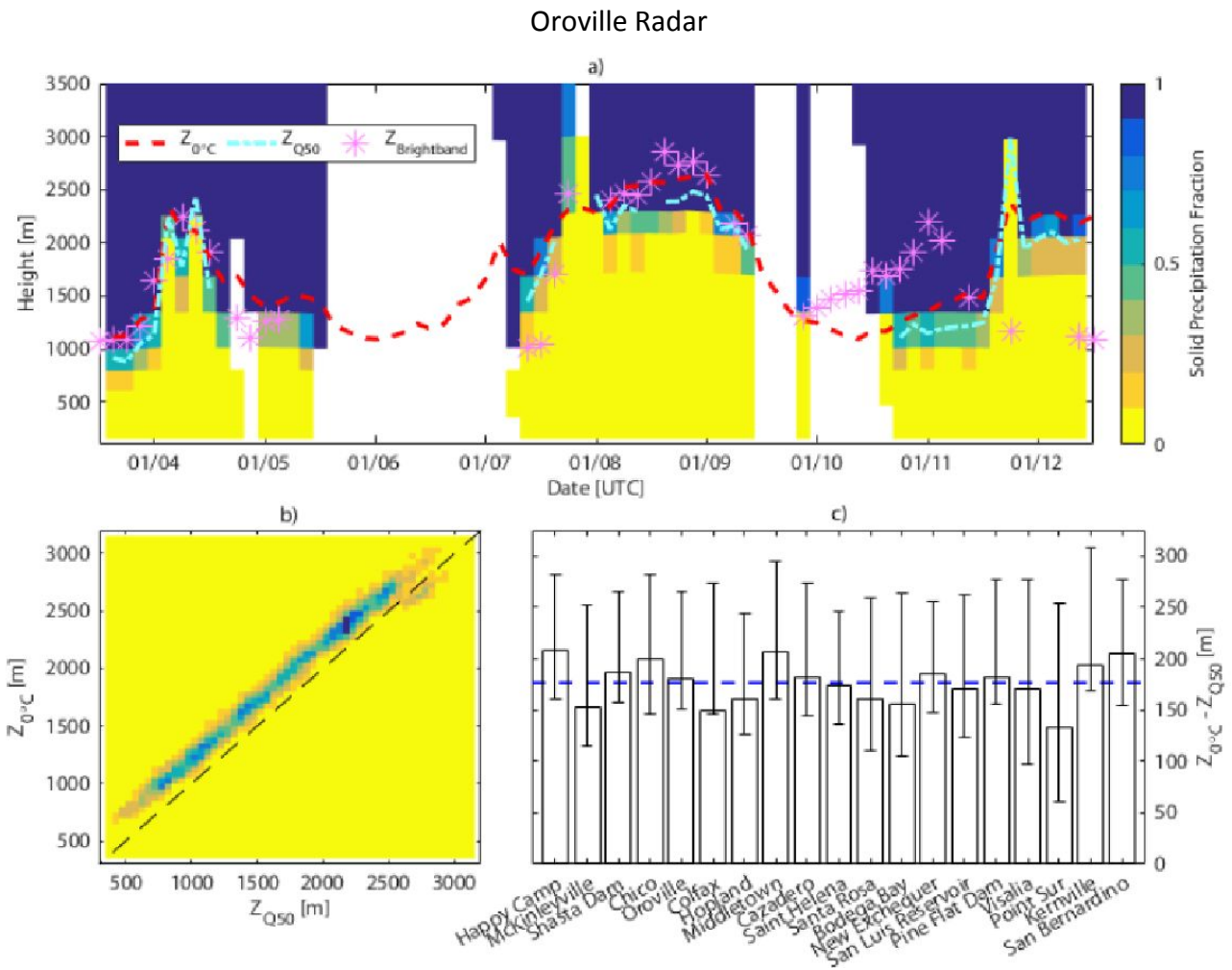
Profiler locations, rain-snow levels, and basin elevation distributions





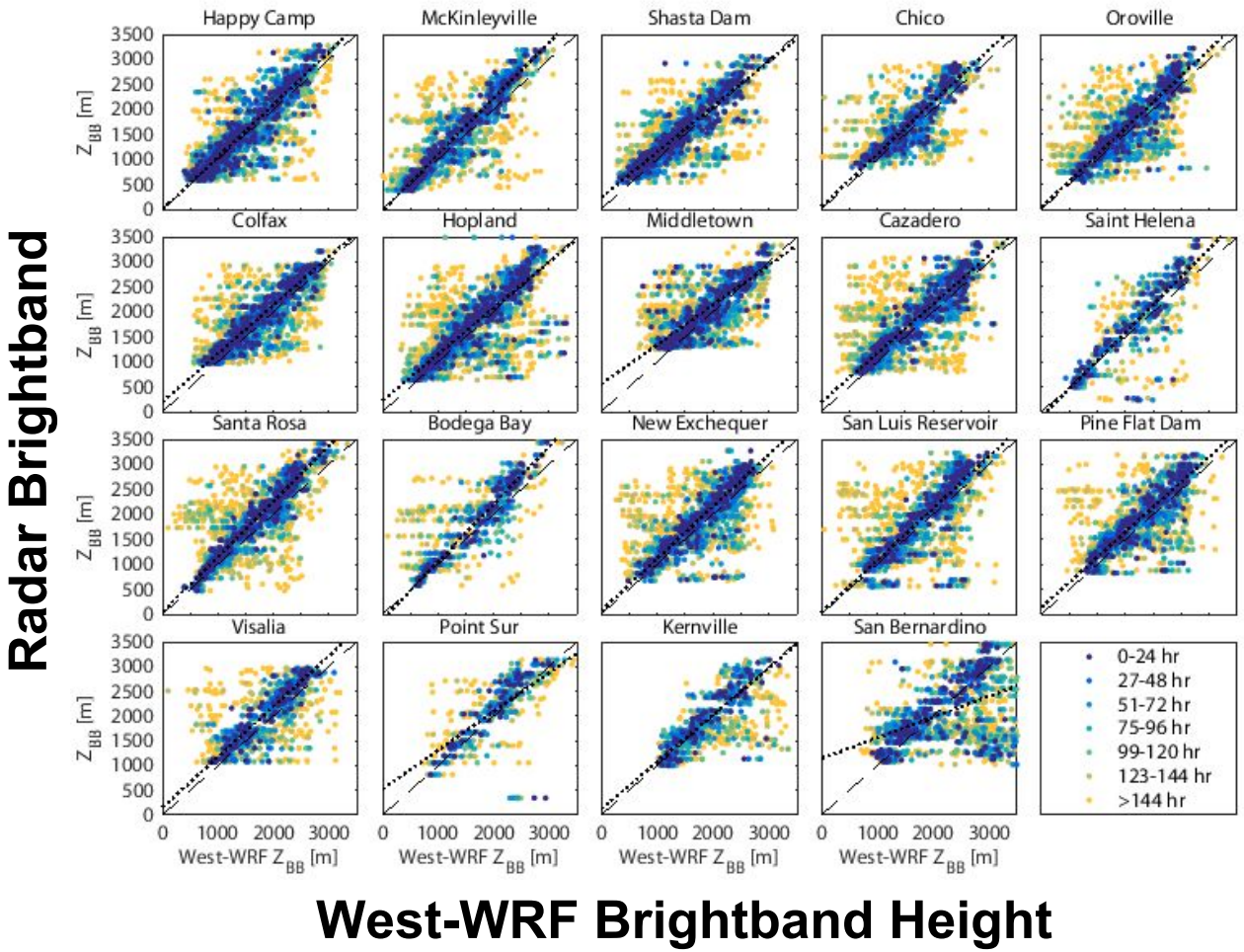


Use of freezing level height vs ZQ50



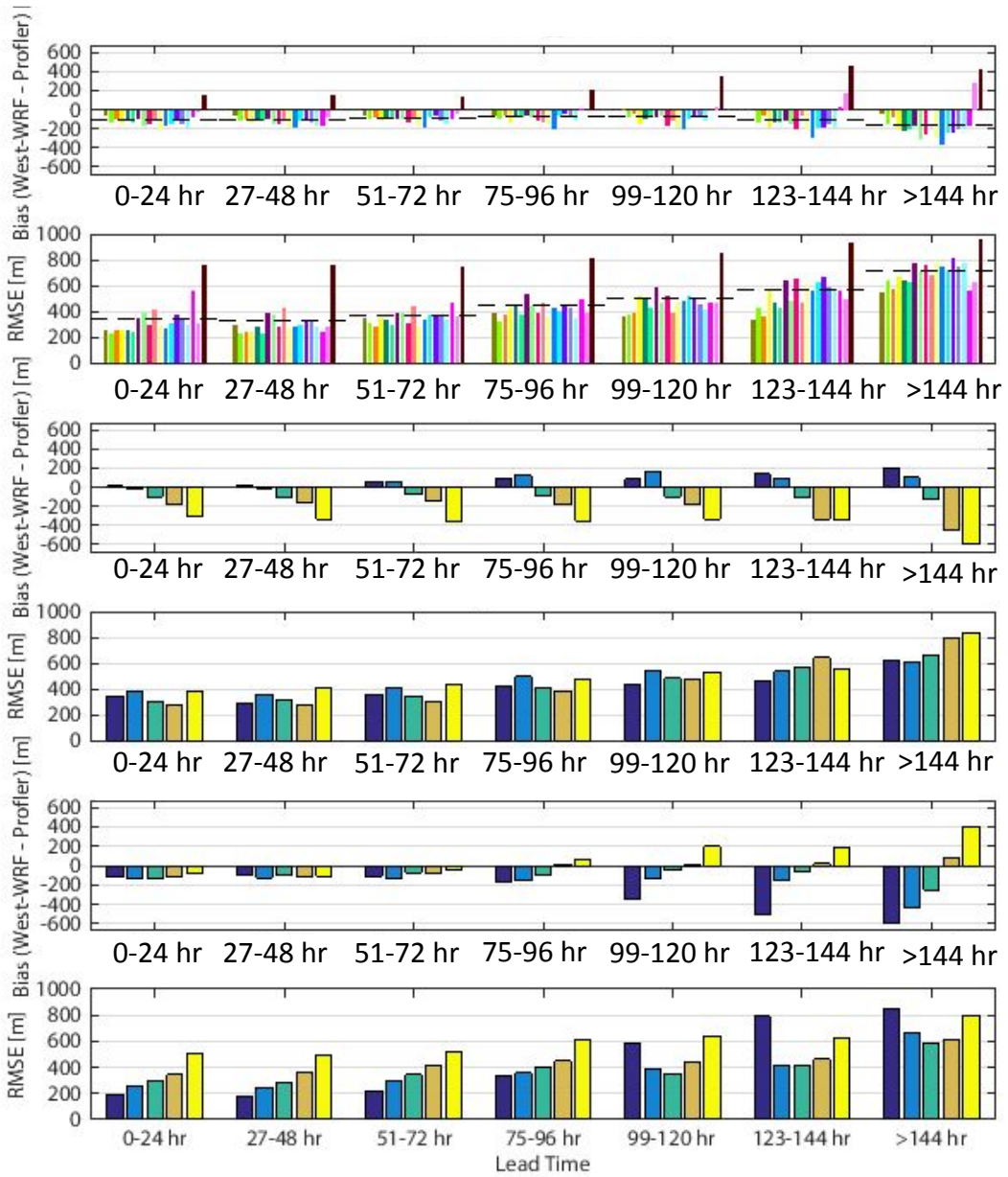
- West-WRF shows elevation of half-melted hydrometeors (ZQ50, approximates brightband) is consistently ~175 m below Z0C
- Use bias offset for all evaluations since ZQ50 not archived for other models

Example of West-WRF Verification



- Rain-snow level vs radar brightband for all 19 sites
- Each plot is radar site
- Colors indicate lead time
- Convergence of forecast and obs. at short lead time
- Range matches obs, but ~1000 m error at longer lead times

West-WRF Verification



Bias by Site

RMSE by Site

Bias by Observed Quintile

RMSE by Observed Quintile

Bias by Forecast Quintile

RMSE by Forecast Quintile

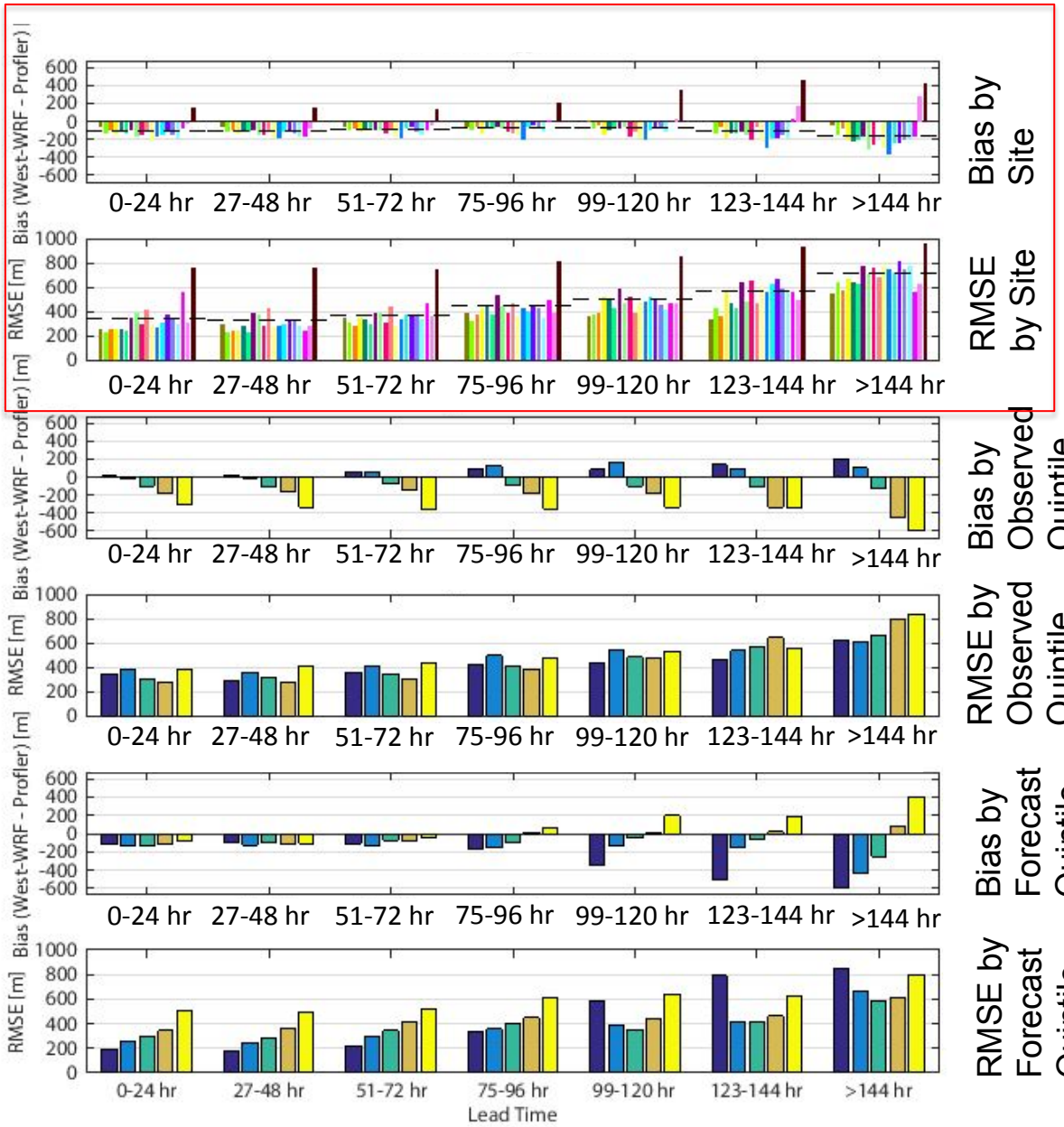
- Happy Camp
- McKinleyville
- Shasta Dam
- Chico
- Oroville
- Colfax
- Hopland
- Middletown
- Cazadero
- Saint Helena
- Santa Rosa
- Bodega Bay
- New Exchequer
- San Luis Reservoir
- Pine Flat Dam
- Visalia
- Point Sur
- Kernville
- San Bernardino

- Observed Qntl. 1 (918 m)
- Observed Qntl. 2 (1366 m)
- Observed Qntl. 3 (1779 m)
- Observed Qntl. 4 (2220 m)
- Observed Qntl. 5 (2776 m)

- Forecast Qntl.1 (776 m)
- Forecast Qntl.2 (1195 m)
- Forecast Qntl.3 (1618 m)
- Forecast Qntl.4 (2087 m)
- Forecast Qntl.5 (2606 m)

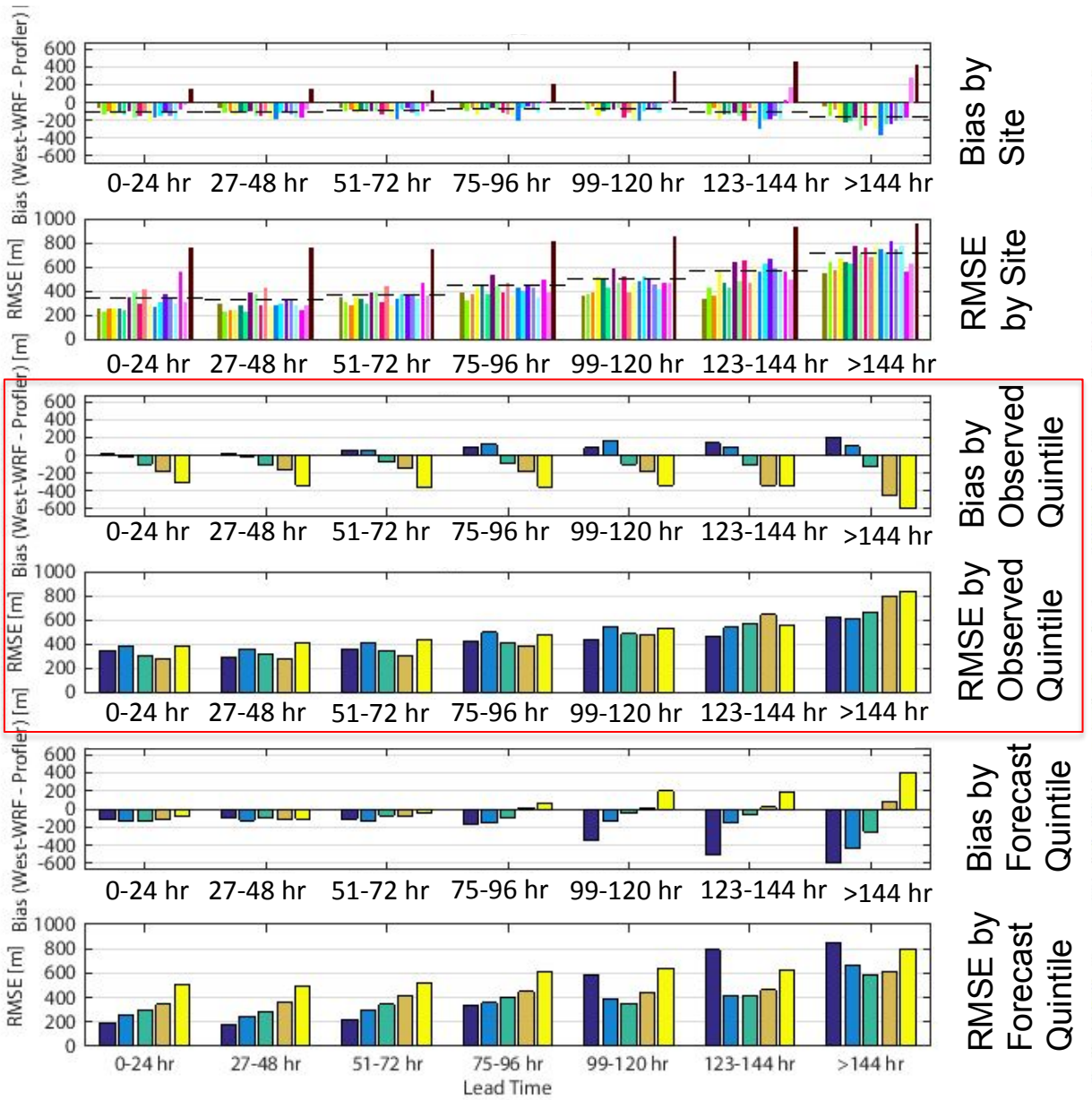
Summary of rain-snow level forecast evaluation statistics: RMSE and bias, sorted by site and forecast lead time

West-WRF Verification



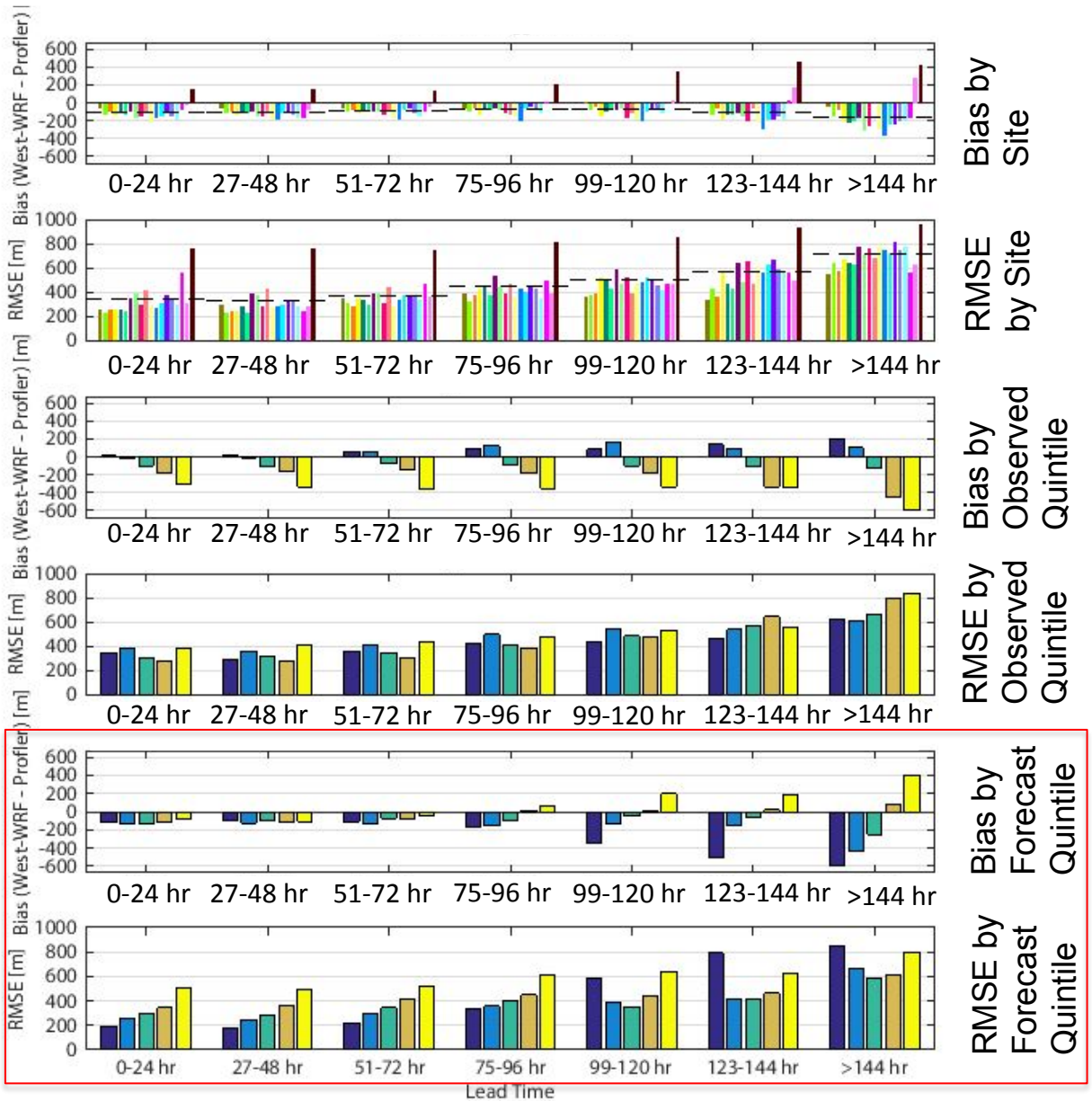
- Slight cold bias that increases with lead time
- RMSE increases from 300m (short lead) to >600m (long lead)

West-WRF Verification



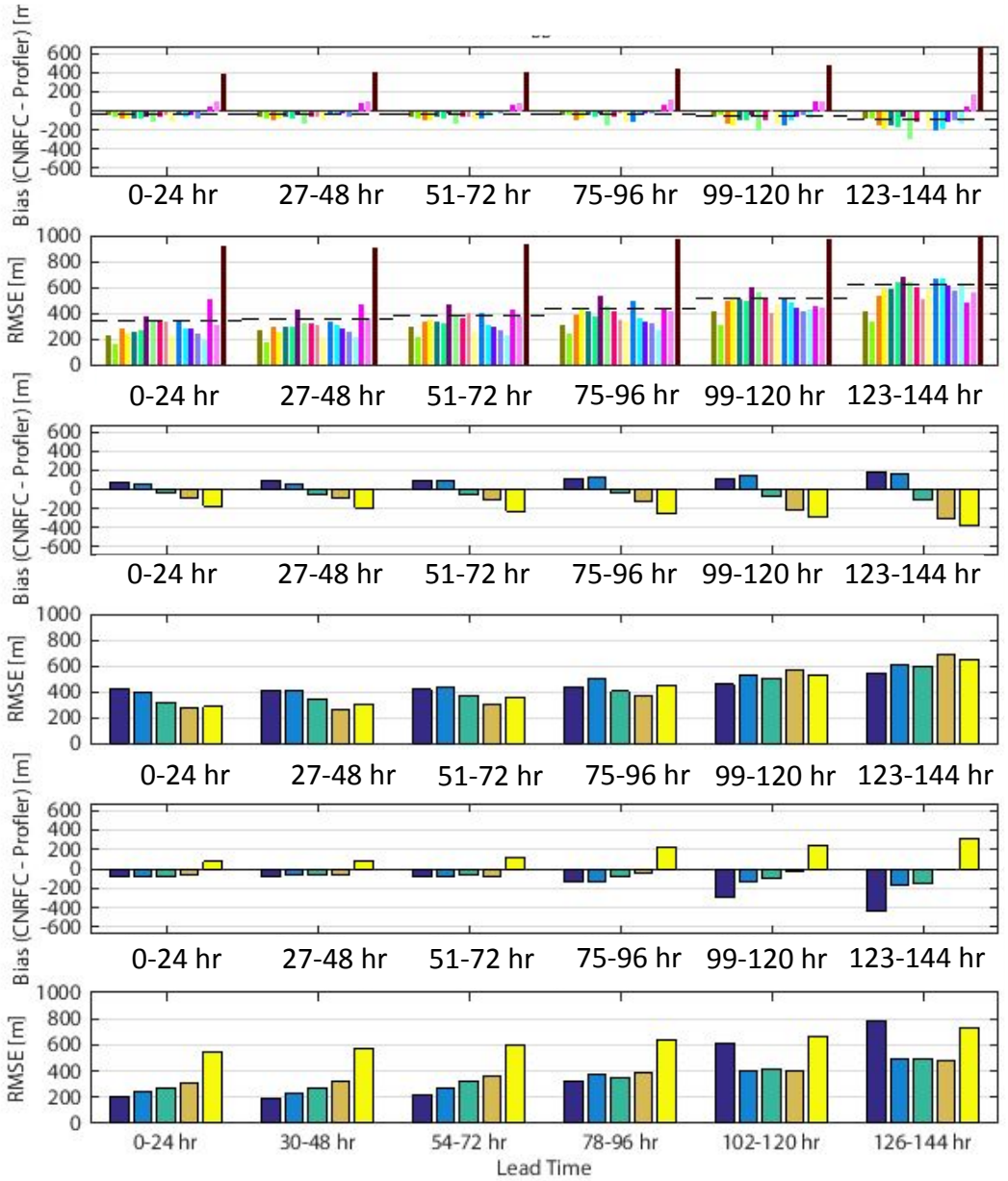
- RMSE and bias sorted by *forecast* rain-snow level quintiles (cold to warm)
- High forecast freezing levels have negative bias (false alarms)
- High forecast freezing levels have higher RMSE

West-WRF Verification



- RMSE and bias sorted by *observed* rain-snow level quantiles (cold to warm)
- High observed freezing levels are underforecast
- Low observed freezing levels are overforecast (failure to capture extremes)

CNRFC Verification



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RMSE by Forecast Quintile

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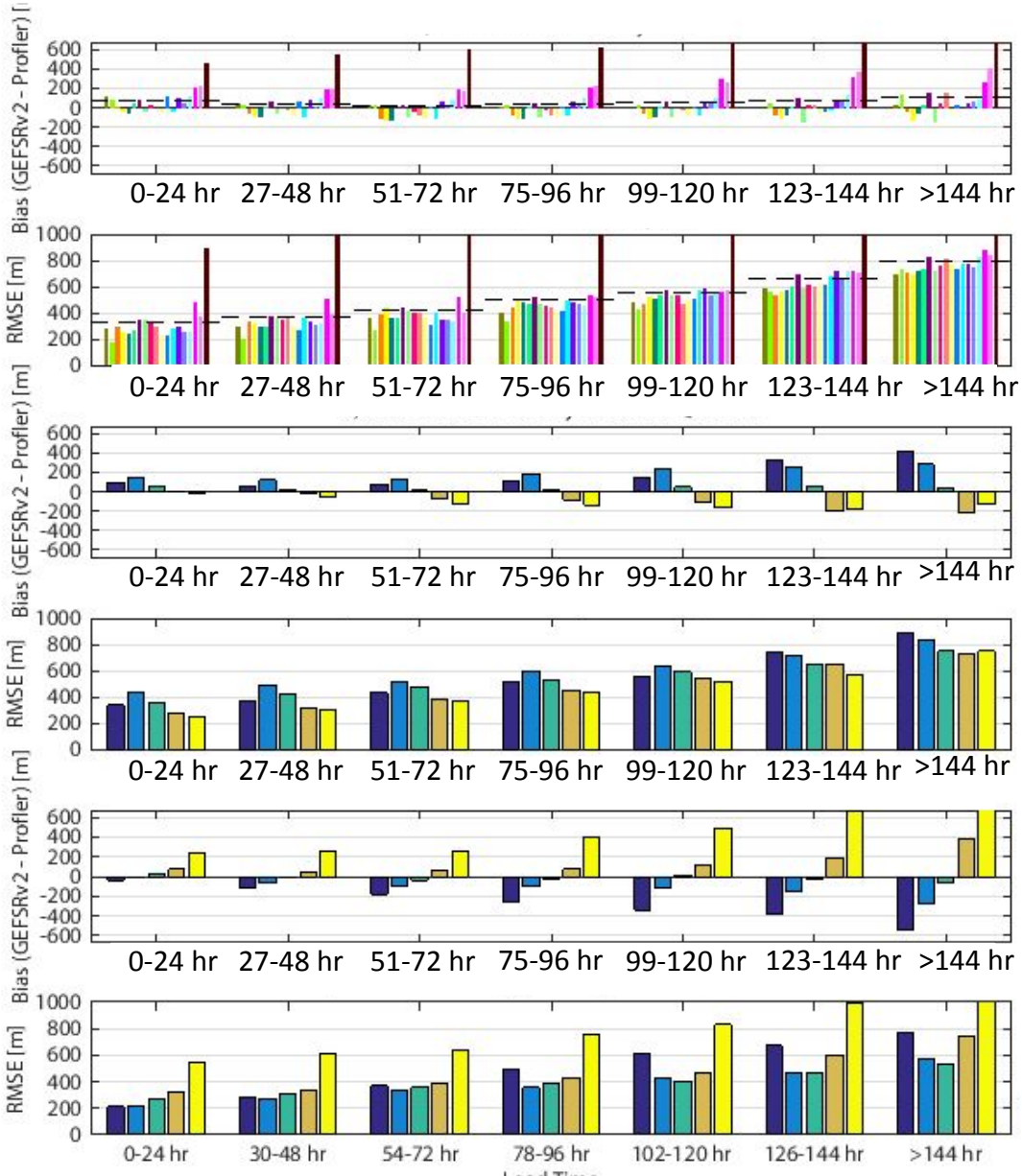
- San Luis Reservoir
- Pine Flat Dam
- Visalia
- Point Sur
- Kernville
- San Bernardino

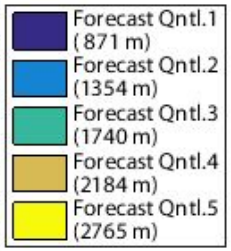
- Observed Qntl. 1 (907 m)
- Observed Qntl. 2 (1375 m)
- Observed Qntl. 3 (1805 m)
- Observed Qntl. 4 (2263 m)
- Observed Qntl. 5 (2805 m)

- Forecast Qntl.1 (871 m)
- Forecast Qntl.2 (1354 m)
- Forecast Qntl.3 (1740 m)
- Forecast Qntl.4 (2184 m)
- Forecast Qntl.5 (2765 m)

- Equivalent summary statistics for CNRFC operational rain-snow level forecasts
- Very similar model performance to West-WRF
- Slightly smaller bias

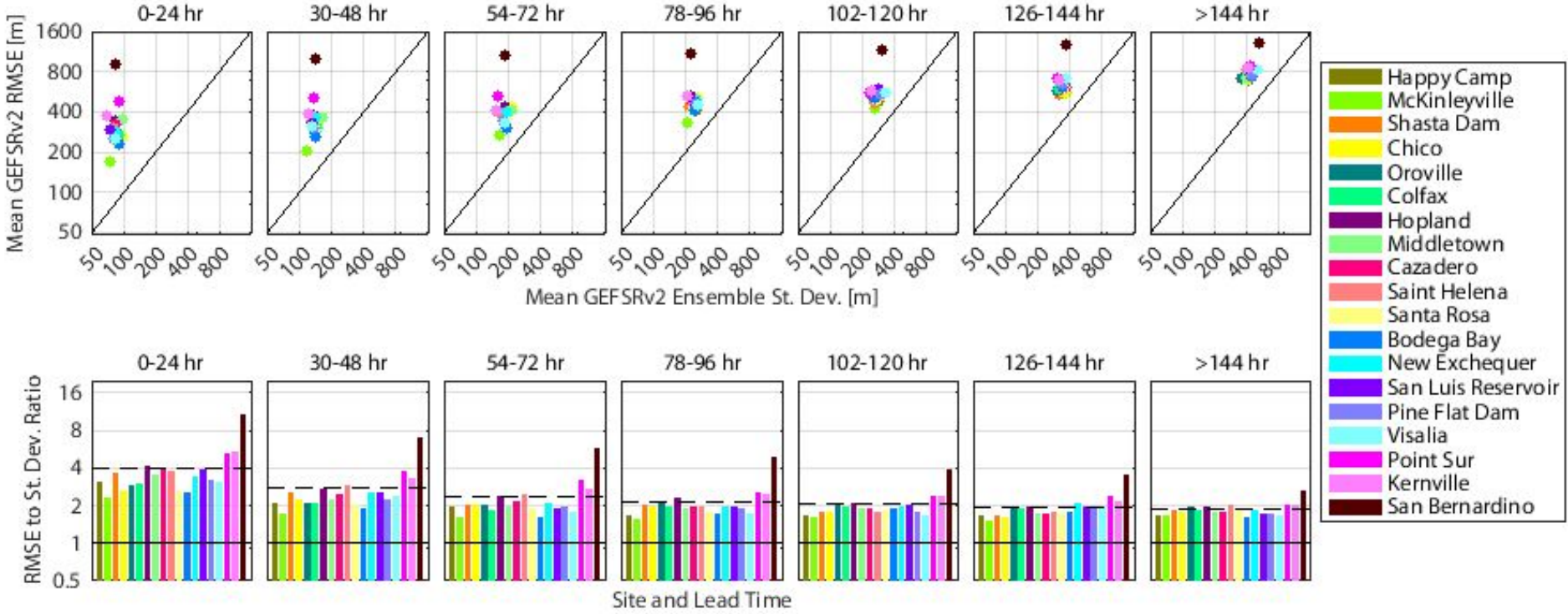
GEFSRv2 Verification





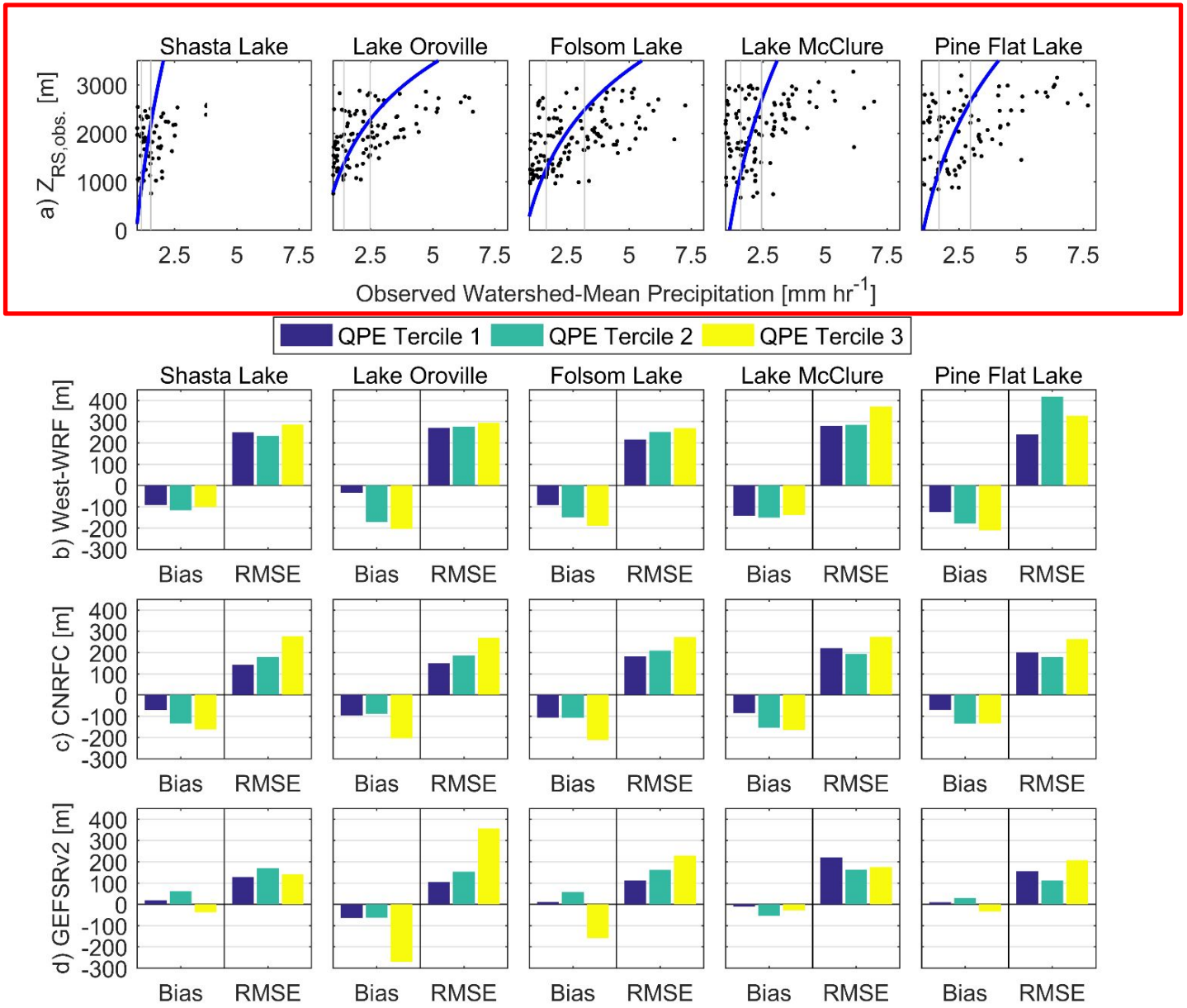
- GEFSRv2 rain-snow level forecast evaluation summary statistics, average of all ensemble members
- Very similar model performance to West-WRF and CNRFC
- Positive bias, higher RMSE

GEFSRv2 Spread vs Forecast Error



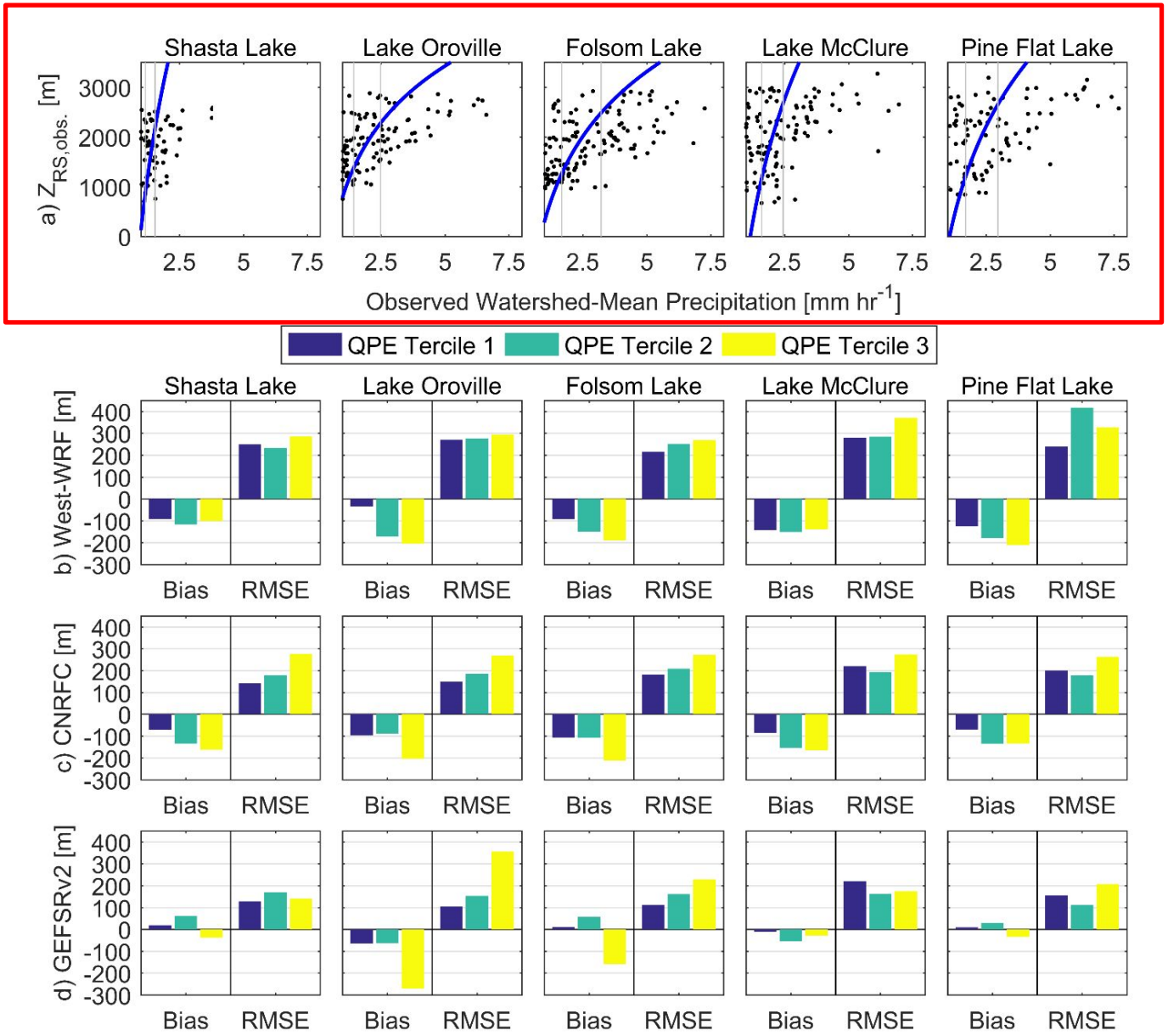
- GEFSRv2 ensemble spread is less than forecast RMSE (by factor of 2-4), consistent across lead times and sites
- This is evidence that GEFSRv2 rain-snow levels are under-dispersed at all lead times, particularly short lead times

Precipitation and rain-snow relationships



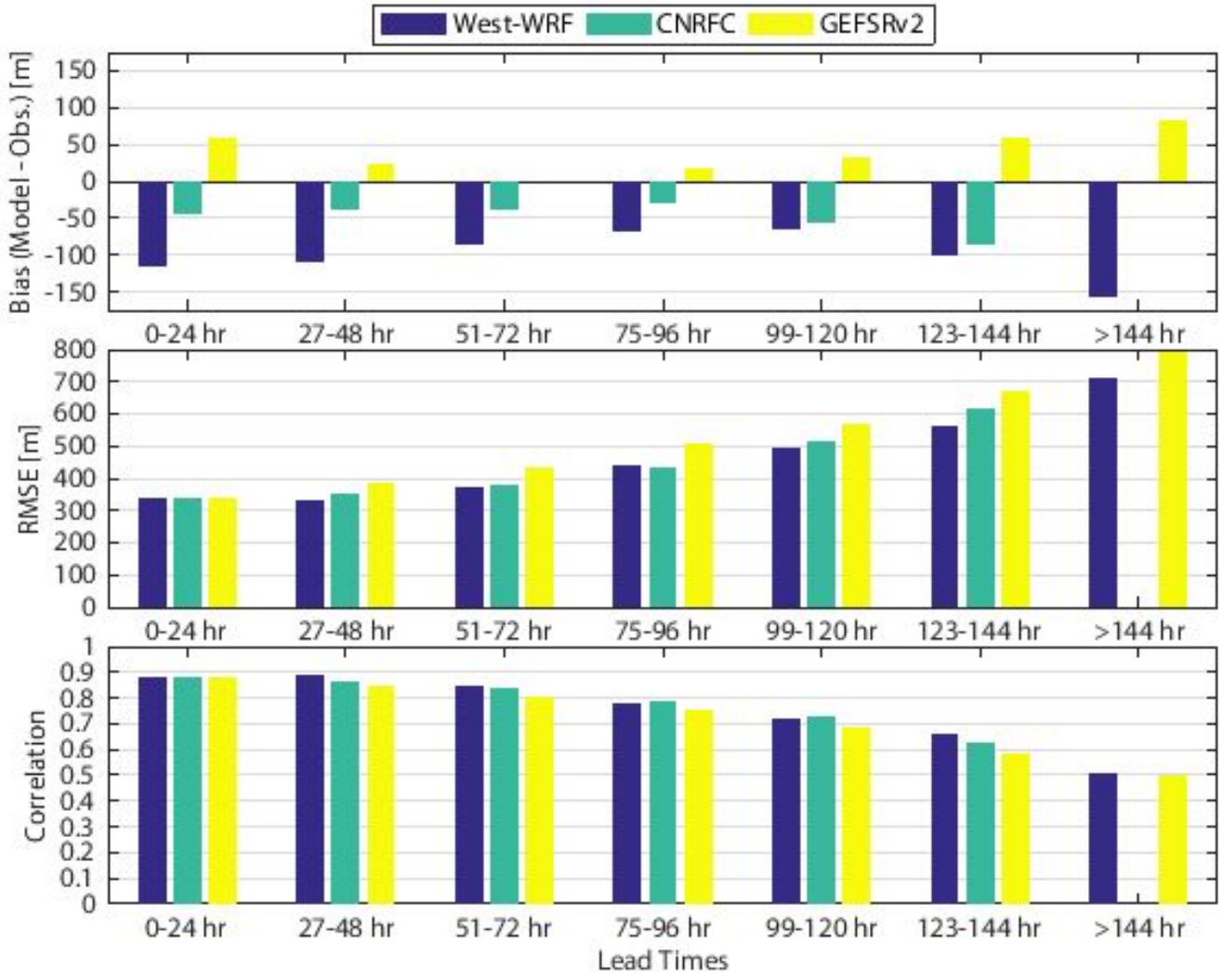
- Examination of observed precipitation in key reservoir watersheds (QPE) against observed rain-snow levels at local radars: strong, positive relationship observed

Precipitation and rain-snow relationships



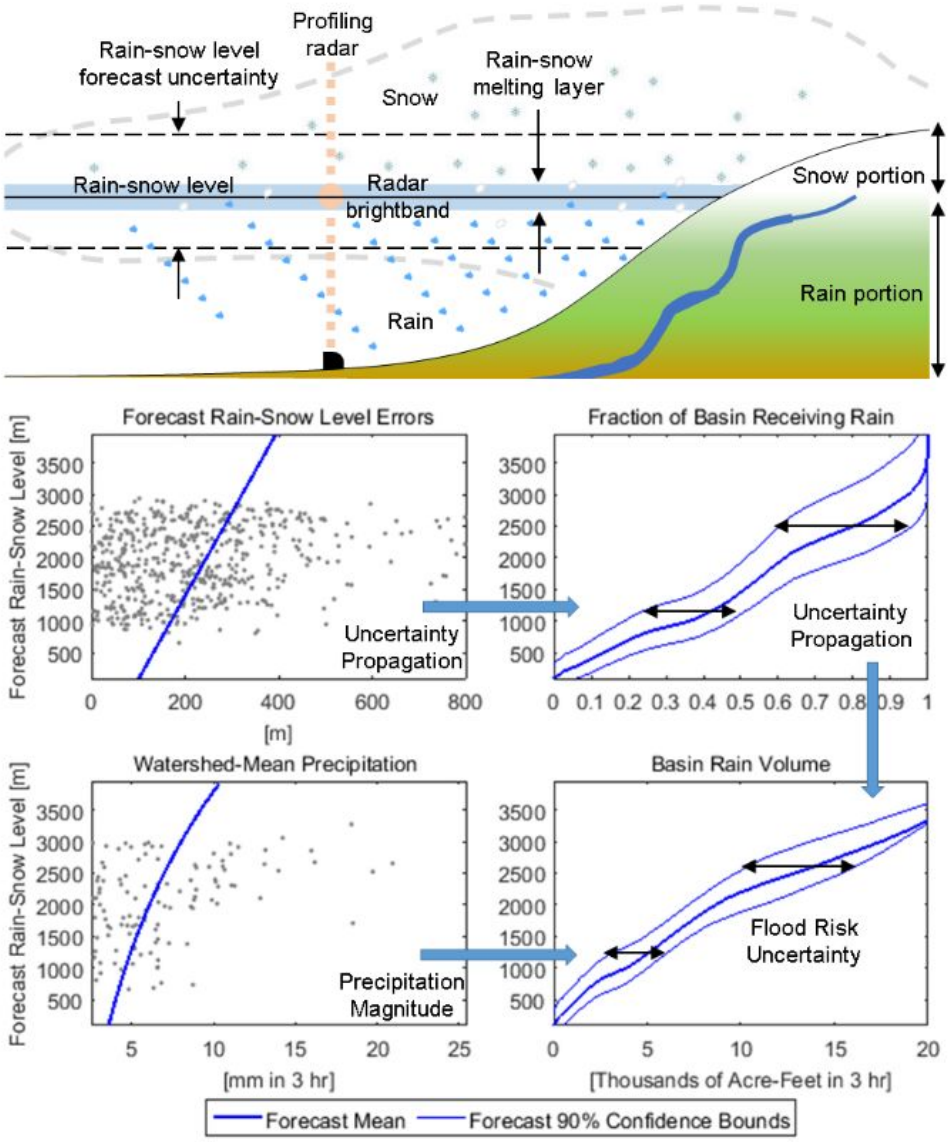
- Rain-snow level forecast errors sorted by precipitation rate
- High precip rates more likely to have associated underforecast rain-snow levels, and greater error magnitudes overall

Summary Statistics



- Small bias w.r.t range of freezing level
- RMSE similar across models, from ~300 m at 1 day lead to >600 m at 5+ day lead; larger than bias
- West-WRF has slightly higher correlation to observations than CNRFC and GE

Pulling it all together…



a) Rain-snow level error magnitudes ***increase*** with rain-snow level

b) This ***causes uncertainty*** in basin area receiving rain to ***increase*** with rain-snow level

c) Precipitation rates ***increase*** with rain-snow level

d) Runoff volume uncertainty ***increases*** dramatically with rain-snow level due to a) and c)

Key Findings

- CA terrain sensitive to observed rain-snow variability
- ZQ50 (brightband) assumed ~175 m below Z0C
- West-WRF forecasts: slight underestimates, especially for warm events and heavy precipitation; errors largest also in these events
- CNRFC: similar to West-WRF, slightly different bias
- GEFSRv2: similar also, ensemble under-dispersed (overconfident)
- Forecast errors are more severe for high rain-snow level events, and for high precipitation events
- Extreme rain-snow levels are low-biased given observations (insufficient extremes), but high-biased given forecasts (false alarms)
- 300-600 m RMSE in rain-snow level forecasts that compounds flood risk in extreme events