Assessment of Streamflow Forecast Skill in the Truckee River Basin

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Abstract

Water supply reliability in the Truckee River basin stands to substantially benefit from forecast-informed reservoir operations(FIRO), especially given expected increases in rain: snow ratios and a transition to earlier runoff under warming climate that current infrastructure and operational rules were not designed for. However, in its position on the lee side of the Sierra Nevada mountains (CA/NV, USA), several unique forecast uncertainties exist that must be considered to mitigate against increased flood risk potential. Both water supply and floods are strongly linked to wintertime atmospheric rivers (AR) but despite improvements in forecasting these events at long lead times, the timing and amount of spillover precipitation onto the lee side remains a key uncertainty. In addition, storm runoff volumes in this basin are highly sensitive to rain-snow elevation, which is also difficult to forecast. Finally, antecedent snowpack and soil conditions have the potential to modulate runoff volumes but factors controlling the strength of these modulations are incompletely understood and monitored. In this study, we assess streamflow forecast skill in the Truckee River to provide a preliminary understanding of potential forecast-related challenges and opportunities for FIRO. To accomplish this, we used an archive of readily available short-range Hydrologic Ensemble Forecast System winter (Oct-Apr) streamflow forecasts for water years 2015-2020 and compared these to observed3-day flows at lead times of 0 to 15 days. We subset the data into AR days, non-AR days and top 10% flow days examined the variance explained between the ensemble median and observed 3-day flows as a function of lead time. We also examined how the observed 3-day flows rank in relation to the ensemble members for each day. We found that forecast accuracy improves considerably starting at a 7-day lead time but tends to be lower for high-flow and AR events relative to non-ARs. We also found the ensembles to have a slight bias toward underprediction and tendency toward under-dispersion (i.e. observed flows were sometimes outside the ensemble range) with this being the case for AR and high flow days for some but not all sites.

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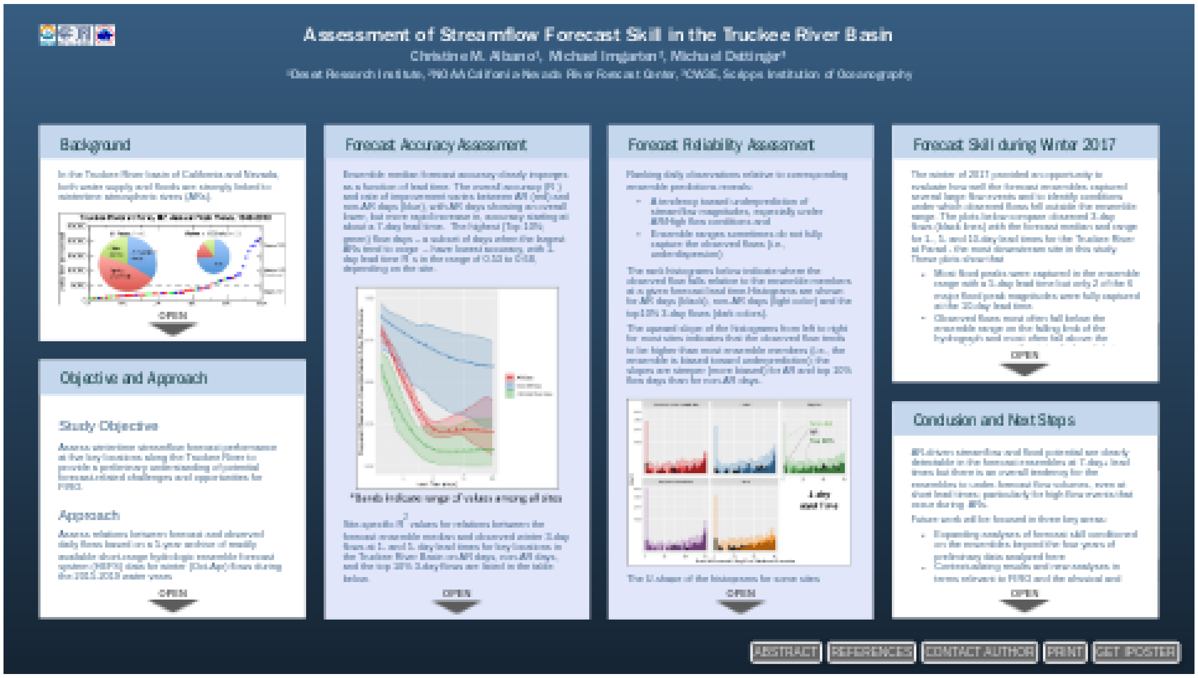

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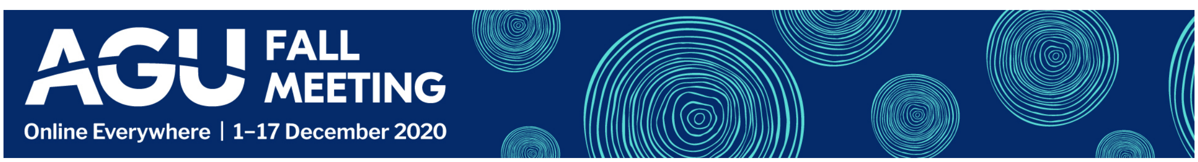
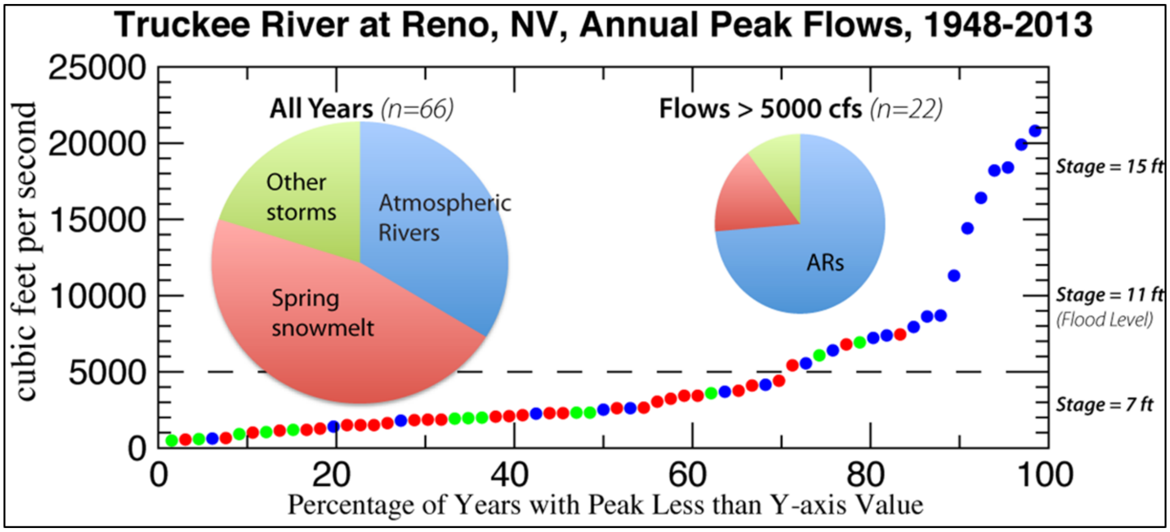


BACKGROUND

In the Truckee River basin of California and Nevada, both water supply and floods are strongly linked to wintertime atmospheric rivers (ARs).



Atmospheric rivers and Truckee River floods. Figure from Albano et al. 2016

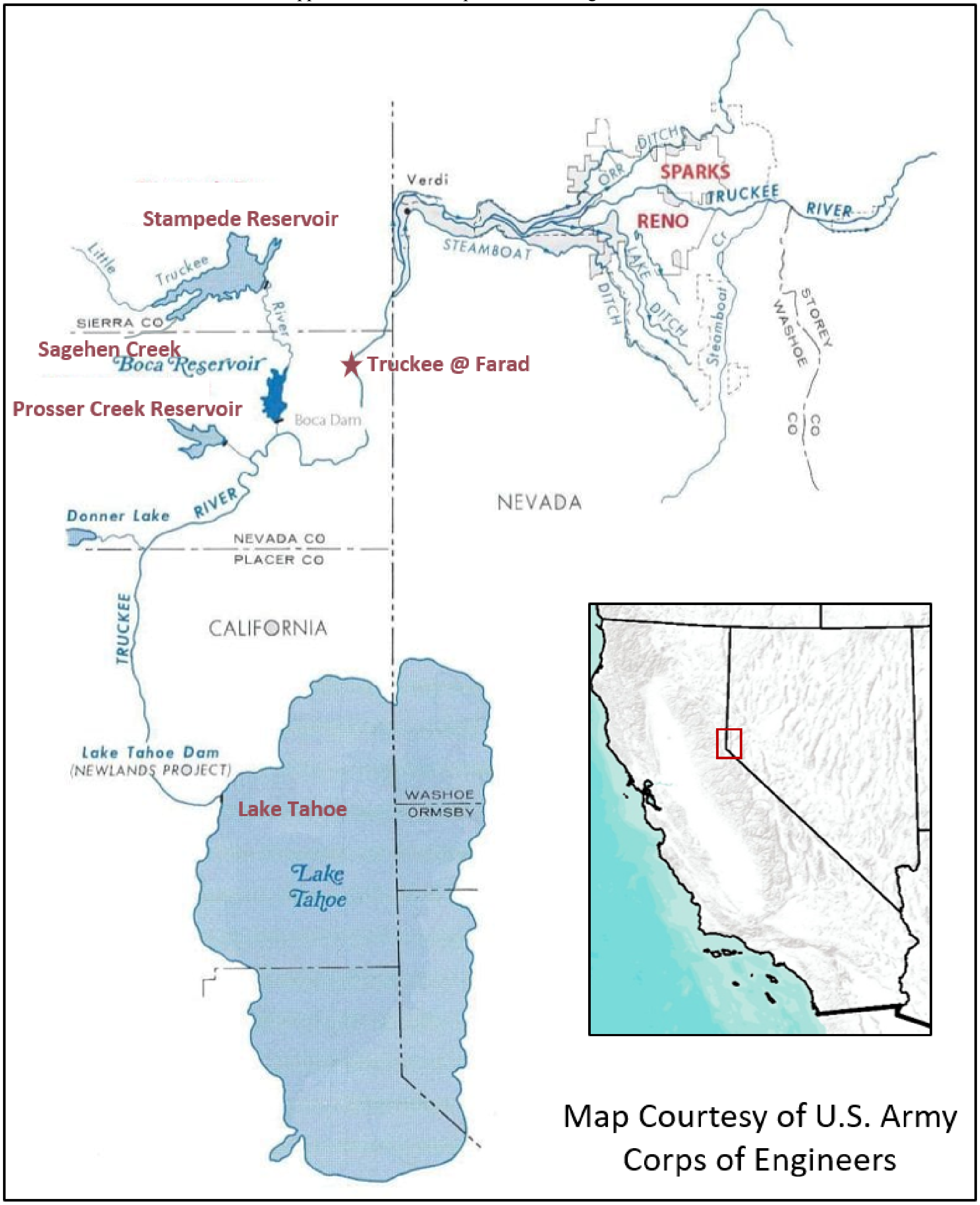
Expected increases in atmospheric river storm intensities, rain:snow ratios, and a transition to earlier runoff under warming climate will stress current infrastructure and reduce the effectiveness of reservoir operations that were designed for stationary climate. Forecast-informed reservoir operations (FIRO) has the potential to mitigate against these impacts but the viability of this strategy is, in part, dependent upon the ability to forecast streamflow with enough reliability that flood risks during AR storms are not increased. Unlike most other AR-influenced basins where FIRO has been explored, the Truckee River has several unique hydrologic forecast uncertainties due to its high elevation and position on the lee side of the Sierra Nevada mountains, including:

- Timing and amount of spillover precipitation over the Sierra Nevada mountain crest
- High sensitivity to elevation of rain:snow transitions during storms
- Influence of both antecedent soil and snowpack conditions

Study Area

The Truckee River originates at 2700 m elevation on the eastern slope of the Sierra Nevada mountain range and flows 195 km northeastward through the the cites of Reno and Sparks to its eventual terminus at Pyramid Lake. This highly managed system includes three dammed natural lakes that serve as water supply reservoirs and four additional flood control reservoirs (Stampede, Boca, Prosser Creek, and Martis Creek) with fixed-date operations in accordance with U.S. Army Corps flood control criteria.

Diverse uses of Truckee River water supplies include municipal, industrial, agricultural, and environmental instream flows.



OBJECTIVE AND APPROACH

Study Objective

Assess wintertime streamflow forecast performance at five key locations along the Truckee River to provide a preliminary understanding of potential forecast-related challenges and opportunities for FIRO.

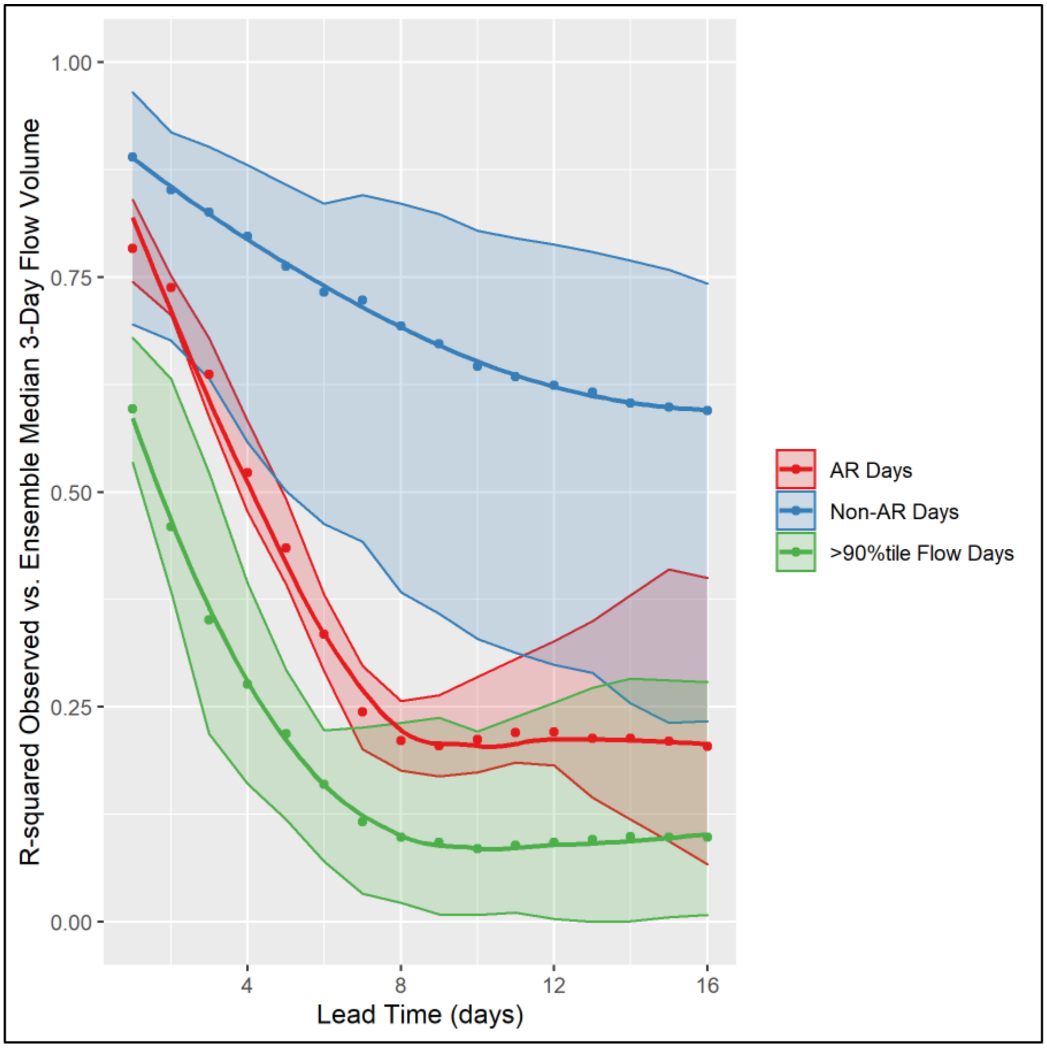
Approach

Assess relations between forecast and observed daily flows based on a 5-year archive of readily available short-range hydrologic ensemble forecast system (HEFS) data for winter (Oct-Apr) flows during the 2015-2019 water years

- Assess and compare forecast accuracy among winter AR (Rutz et al. 2015, IVT > 250 kg/ms), non-AR, and high flow (>90th percentile) event days
- Assess and compare forecast ensemble reliability and consistency relative to observed

FORECAST ACCURACY ASSESSMENT

Ensemble median forecast accuracy clearly improves as a function of lead time. The overall accuracy (R^2) and rate of improvement varies between AR (red) and non-AR days (blue), with AR days showing an overall lower, but more rapid increase in, accuracy starting at about a 7-day lead time. The highest (Top 10%; green) flow days – a subset of days when the largest ARs tend to occur – have lowest accuracy, with 1-day lead time R^2s in the range of 0.53 to 0.68, depending on the site.



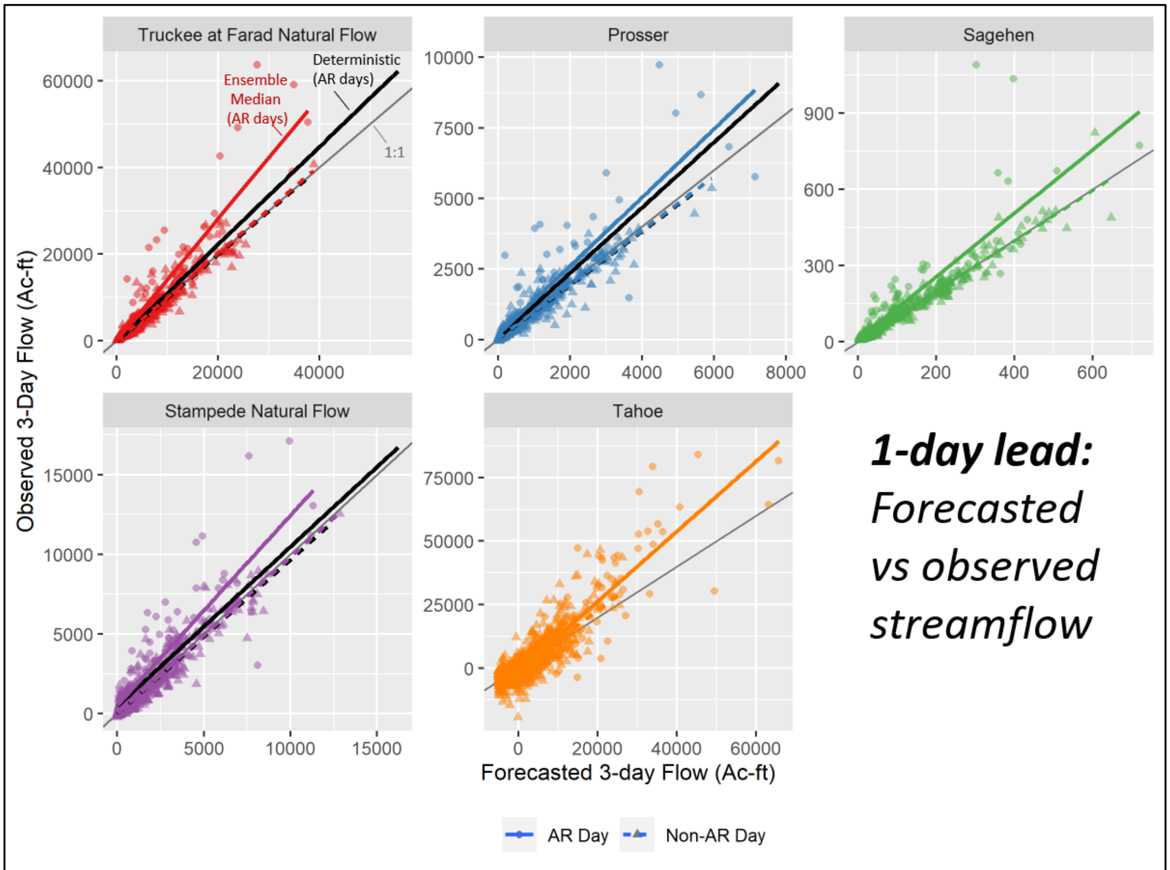
*Bands indicate range of values among all sites

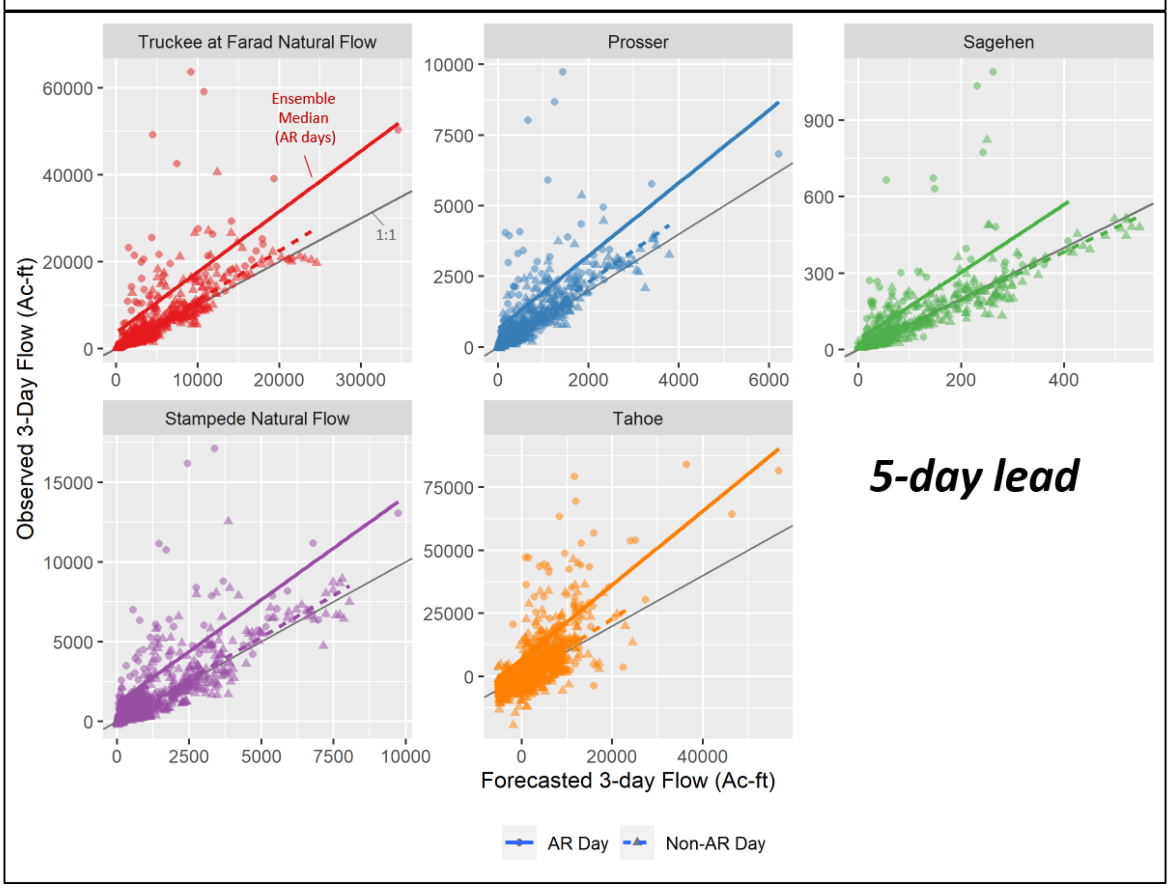
Site-specific R^2 values for relations between the forecast ensemble median and observed winter 3-day flows at 1- and 5- day lead times for key locations in the Truckee River Basin on AR days, non-AR days, and the top 10% 3-day flows are listed in the table below.

	Average Daily Inflow (cfs)	1-Day Lead R^2			5-Day Lead R^2		
		Top 10%	AR	Non-AR	Top 10%	AR	Non-AR
Truckee R. at Farad	506	0.62	0.84	0.94	0.17	0.42	0.81
Prosser Reservoir	76	0.55	0.79	0.94	0.12	0.39	0.84
Stampede Reservoir	138	0.60	0.78	0.91	0.28	0.49	0.80
Lake Tahoe	156	0.68	0.76	0.69	0.29	0.42	0.50
Sagehen Creek	9.5	0.53	0.74	0.97	0.24	0.45	0.86

*Greener shading indicates better forecast accuracy

Scatterplots and the fitted regression lines between the forecast ensemble median (colored) and observed flows at 1- and 5-day lead times are shown below. The relationships between the deterministic forecast (black) and observed are also shown as a reference for some sites. Separate regressions are shown for AR days (solid line) and non-AR days (dashed line) .





These results illustrate:

- Improvement of forecast accuracy at shorter lead times.
- A tendency toward underprediction of flow magnitudes on AR days (shown by the regression lines falling above the 1:1 line). This tendency occurs moreso for the forecast ensemble median which, unlike the deterministic forecast, is

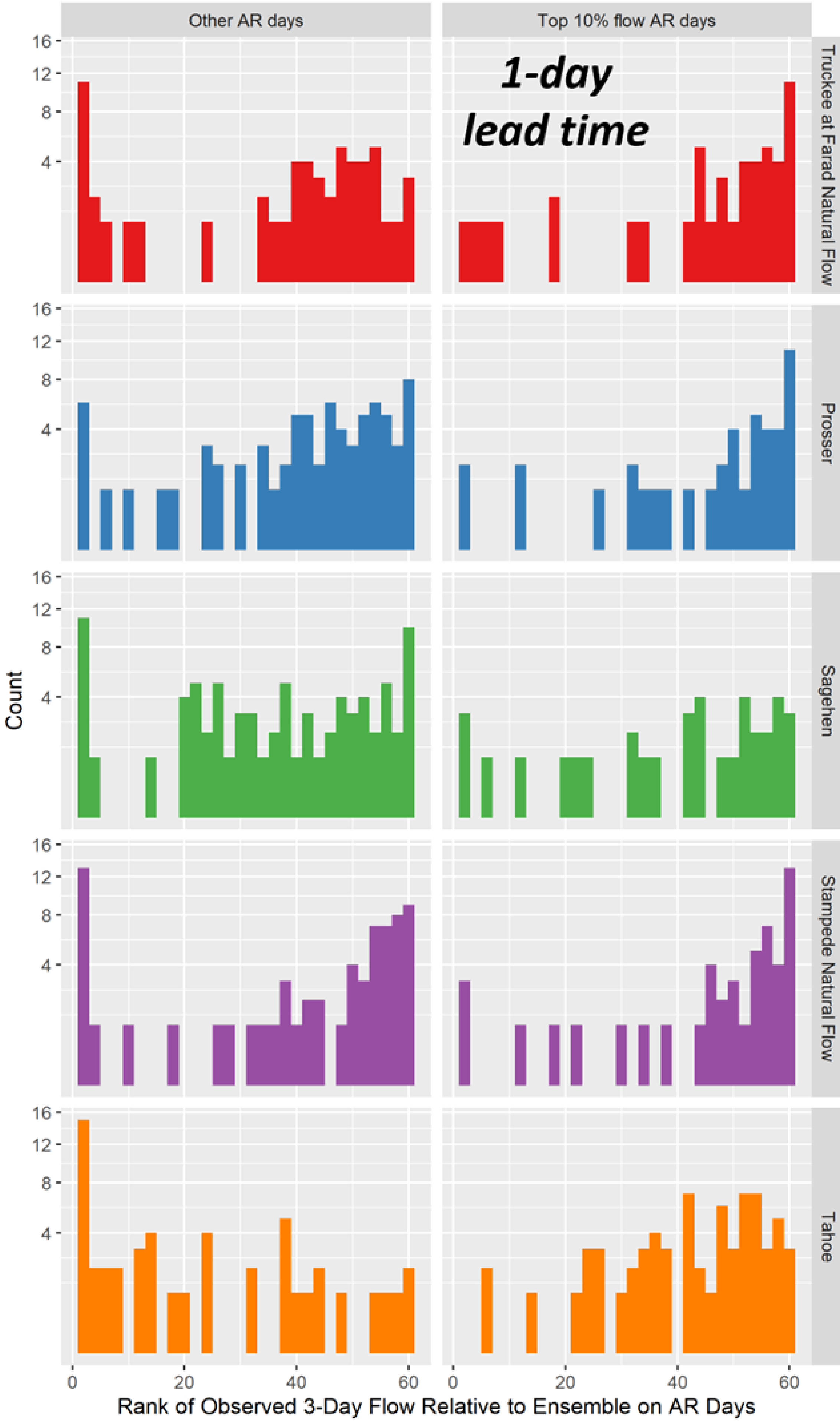
influenced by climatology.

FORECAST RELIABILITY ASSESSMENT

Ranking daily observations on AR days relative to corresponding ensemble predictions reveals:

- A tendency toward underprediction of streamflow magnitudes, especially for top 10% flow days
- Ensemble ranges sometimes do not fully capture the observed flows (i.e., underdispersion), especially for AR days with lower flow magnitudes
- Sites higher in the watershed (Tahoe and Sagehen) exhibited less bias relative to more downstream sites

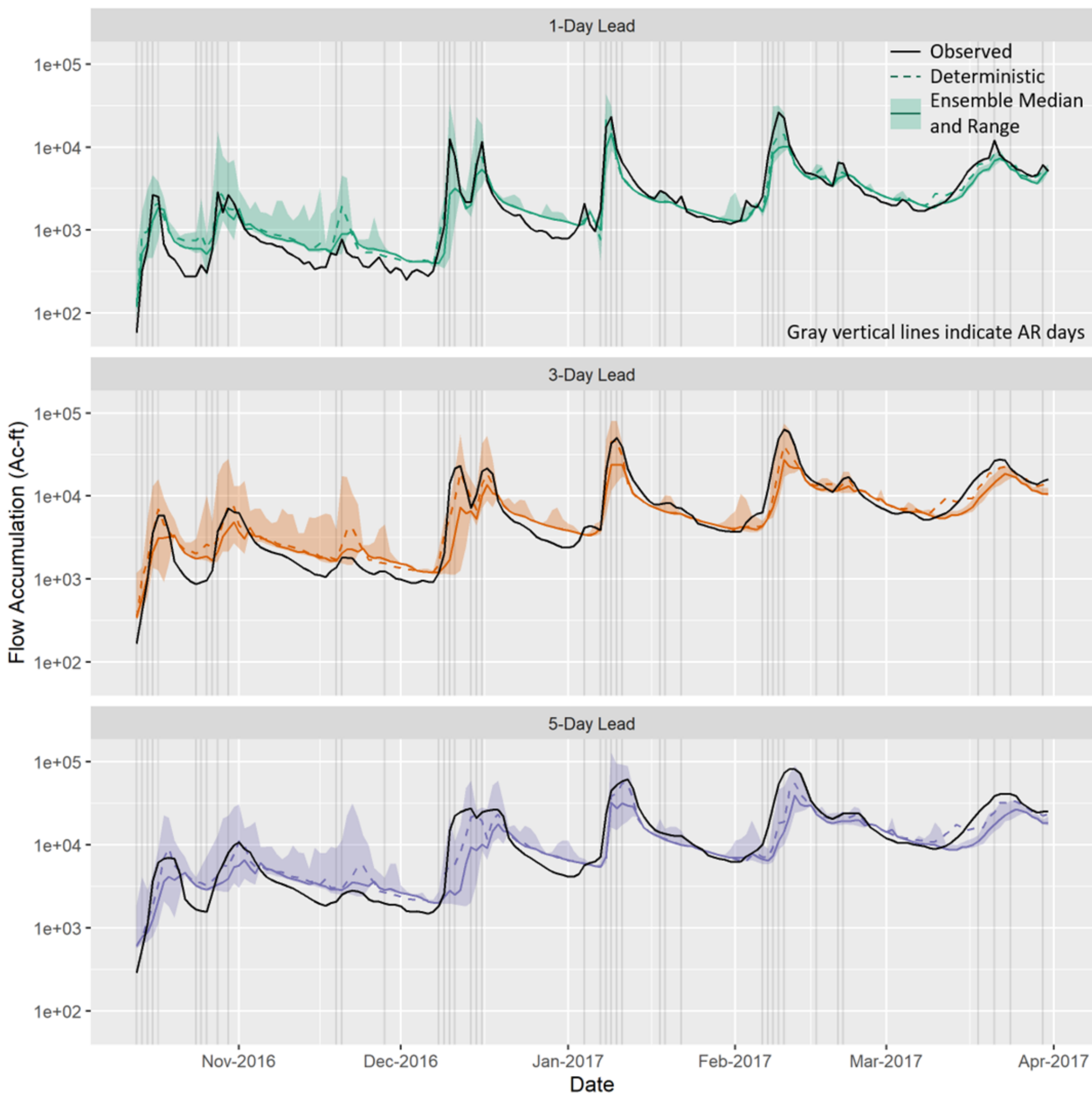
The rank histograms below indicate where the observed flow falls relative to the ensemble members at a one-day lead time. The upward slope of the histograms from left to right for most sites indicates that the observed flow tends to be higher than most ensemble members (i.e., the ensemble is biased toward underprediction); the slopes are generally steeper (more biased) for top 10% flow days.The U-shape of the histograms for some sites indicate under-dispersion - meaning that the observed flows sometimes fall outside of the ensemble range.


Other AR days
Top 10% flow AR days
1-day
lead time
Truckee at Farad Natural Flow
Prosser
Sagehen
Stampede Natural Flow
Tahoe
Count
16
12
8
4
0
20
40
60
Rank of Observed 3-Day Flow Relative to Ensemble on AR Days

FORECAST SKILL DURING WINTER 2017

The winter of 2017 provided an opportunity to evaluate how well the forecast ensembles captured several large flow events and to identify conditions under which observed flows fell outside the ensemble range. The plots below compare observed, deterministic forecast, and ensemble forecast median and range for 1-, 3- and 5-day lead times for the Truckee River at Farad - the most downstream site in this study. These plots show that

- Most flood peaks were captured in the ensemble range at 1- to 5-day lead times.
- Observed flows most often fall outside the ensemble range on the rising and falling limbs of the hydrograph and during non-AR periods when the ensemble range is narrow (i.e., due to lack of precipitation in the forecast)



CONCLUSION AND NEXT STEPS

AR-driven streamflow and flood potential are clearly detectable in the forecast ensembles at 7-day+ lead times but there is an overall tendency for the ensembles to under-forecast flow volumes, even at short lead times; particularly for high flow events that occur during ARs.

Future work will be focused in three key areas:

- Expanding analyses of forecast skill conditioned on the ensembles beyond the four years of preliminary data analyzed here
- Contextualizing results and new analyses in terms relevant to FIRO and the physical and operational constraints within the Truckee River system
- Understanding the relative contributions of quantitative precipitation forecast uncertainty, storm characteristics, and antecedent conditions of soil and snow to uncertainties and biases in hydrologic forecasts

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ABSTRACT

Water supply reliability in the Truckee River basin stands to substantially benefit from forecast-informed reservoir operations (FIRO), especially given expected increases in rain:snow ratios and a transition to earlier runoff under warming climate that current infrastructure and operational rules were not designed for. However, in its position on the lee side of the Sierra Nevada mountains (CA/NV, USA), several unique forecast uncertainties exist that must be considered to mitigate against increased flood risk potential. Both water supply and floods are strongly linked to wintertime atmospheric rivers (AR) but despite improvements in forecasting these events at long lead times, the timing and amount of spillover precipitation onto the lee side remains a key uncertainty. In addition, storm runoff volumes in this basin are highly sensitive to rain-snow elevation, which is also difficult to forecast. Finally, antecedent snowpack and soil conditions have the potential to modulate runoff volumes but factors controlling the strength of these modulations are incompletely understood and monitored. In this study, we assess streamflow forecast skill in the Truckee River to provide a preliminary understanding of potential forecast-related challenges and opportunities for FIRO. To accomplish this, we used an archive of readily available short-range Hydrologic Ensemble Forecast System winter (Oct-Apr) streamflow forecasts for water years 2015-2020 and compared these to observed 3-day flows at lead times of 0 to 15 days. We subset the data into AR days, non-AR days and top 10% flow days examined the variance explained between the ensemble median and observed 3-day flows as a function of lead time. We also examined how the observed 3-day flows rank in relation to the ensemble members for each day. We found that forecast accuracy improves considerably starting at a 7-day lead time but tends to be lower for high-flow and AR events relative to non-ARs. We also found the ensembles to have a slight bias toward underprediction and tendency toward under-dispersion (i.e. observed flows were sometimes outside the ensemble range) with this being the case for AR and high flow days for some but not all sites.

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