Benchmarking different approaches for harnessing predictability in climate and hydrologic initial conditions for seasonal streamflow forecasting

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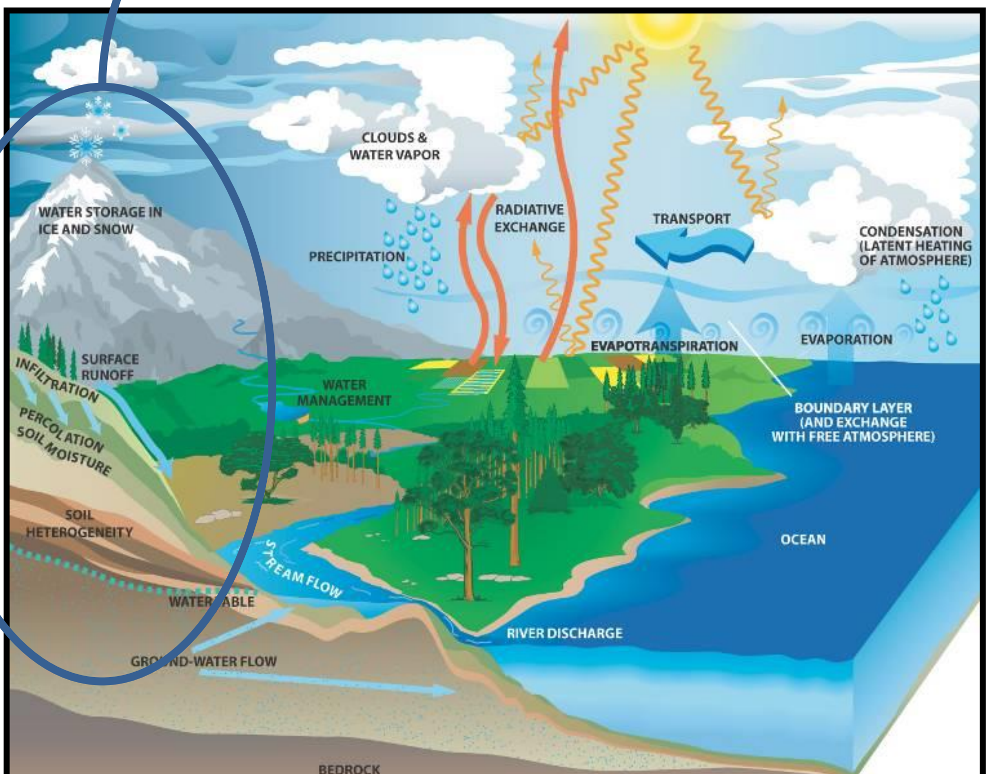
2016 HEPEX Workshop
Ensemble for better hydrological forecasts
June 8, 2016

Motivation

hydrological predictability (land)



Water Cycle (from NASA)

Hydrological Prediction:

How well can we estimate **water stored on the land**?

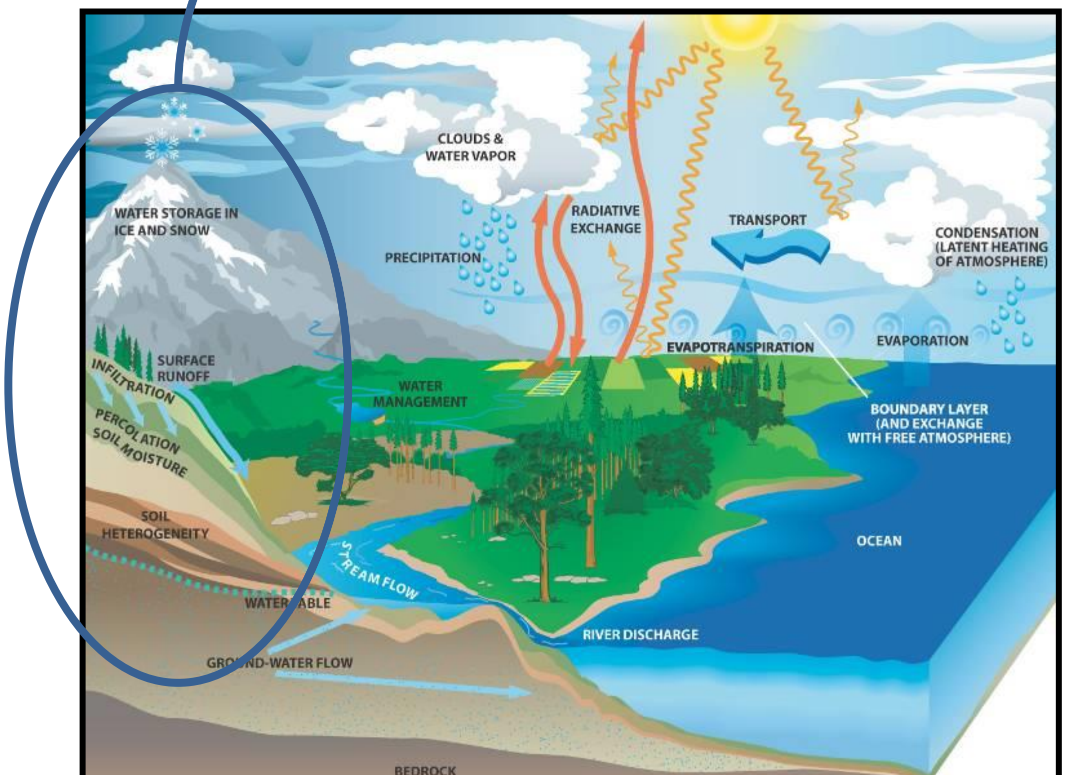
- Statistical and dynamical approaches.
- Mostly helpful in snowmelt-dominated regions.
- Opportunities to improve with advances in process-based models, data assimilation, increased compute power.

Dynamical (ESP)

Motivation

Opportunities for prediction

hydrological predictability (land)



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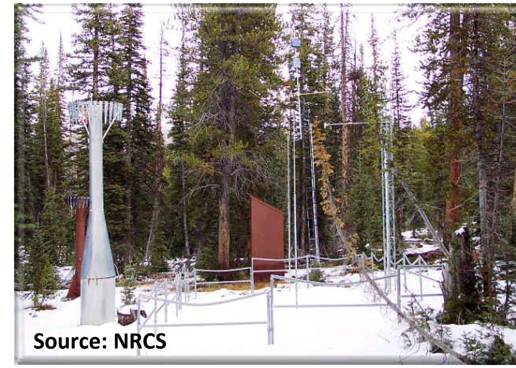
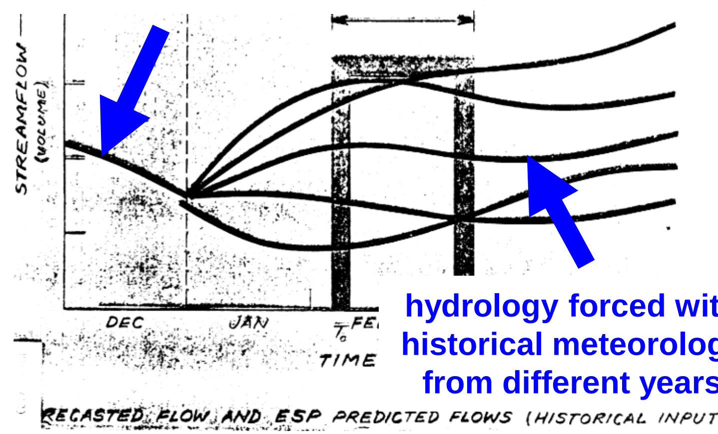


April-July volume Weber @ Oakley =
+ 3.50 * Apr 1st Smith & Morehouse (SMMU1) SWE
+ 1.66 * Apr 1st Trial Lake (TRLU1) SWE
+ 2.40 * Apr 1st Chalk Creek #1 (CHCU1) SWE
- 28.27

Statistical with *in situ* observations

Hydrology model forced with recent meteorological observations

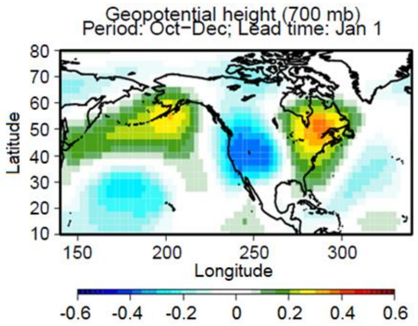


hydrology forced with historical meteorology from different years

Dynamical (ESP)

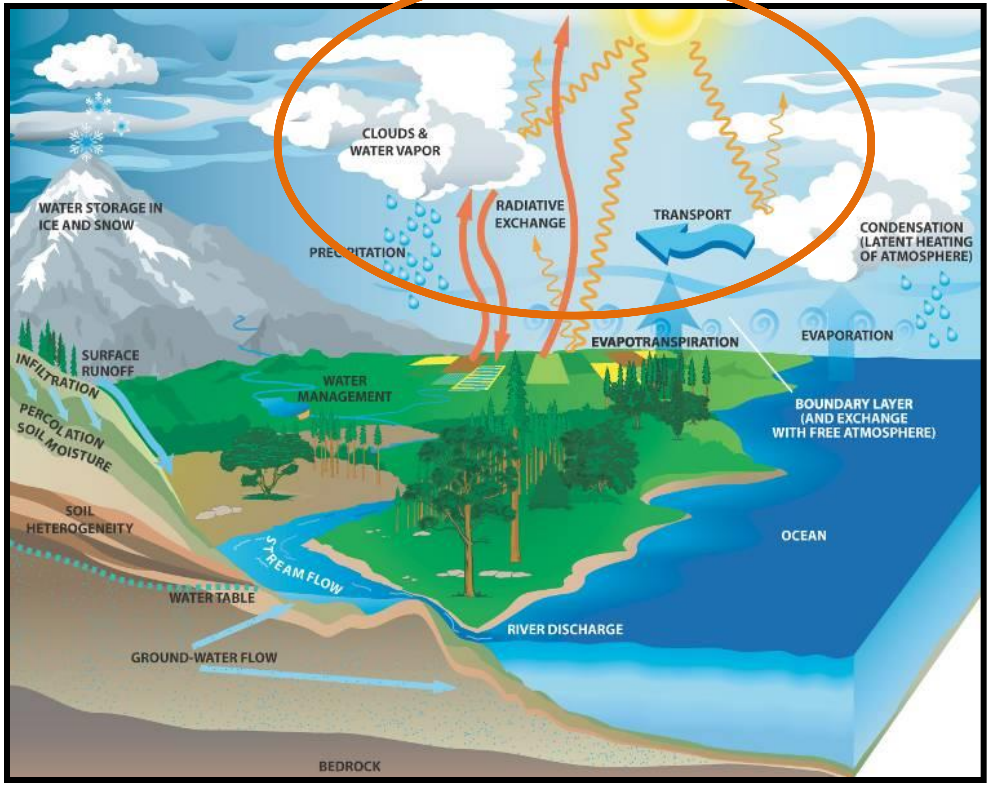
Motivation

Opportunities for prediction



Reanalysis data

meteorological predictability (climate)



Water Cycle (from NASA)

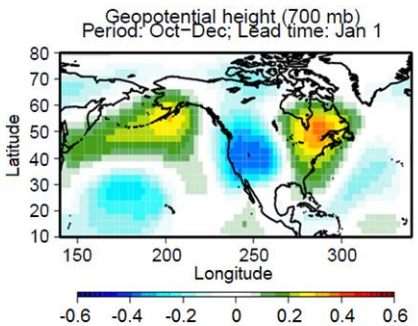
Climate indices

Meteorological predictability:

How well can we forecast the **weather and climate**?

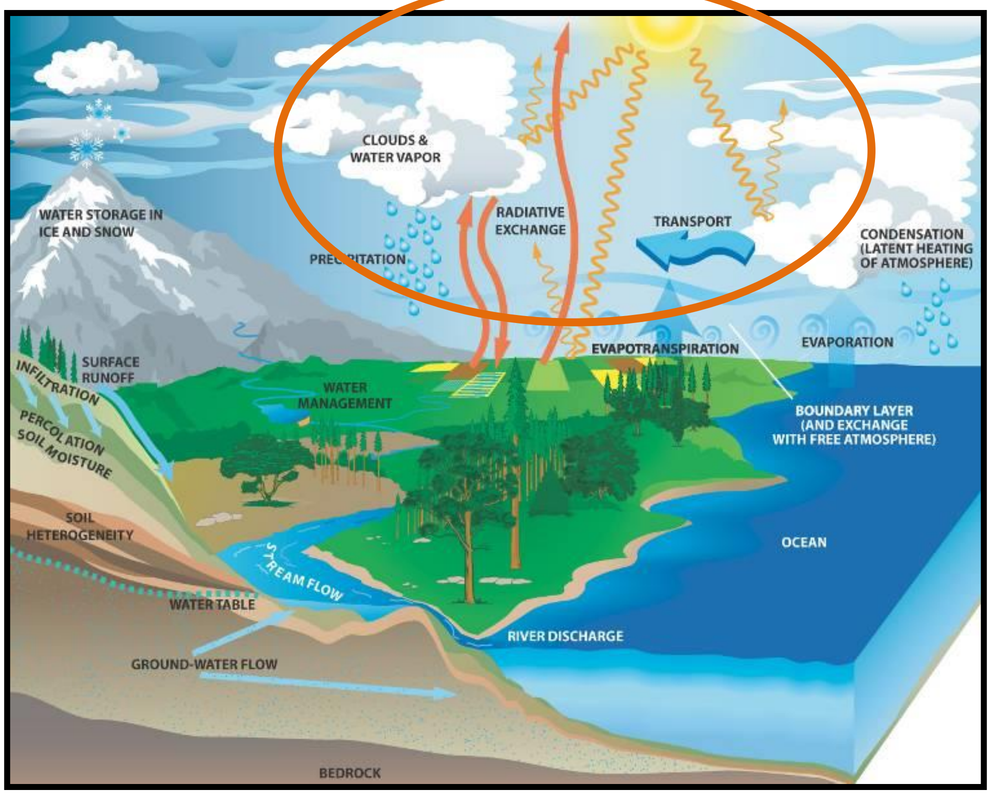
Motivation

Opportunities for prediction



Reanalysis data

meteorological predictability (climate)



Water Cycle (from NASA)

Climate indices

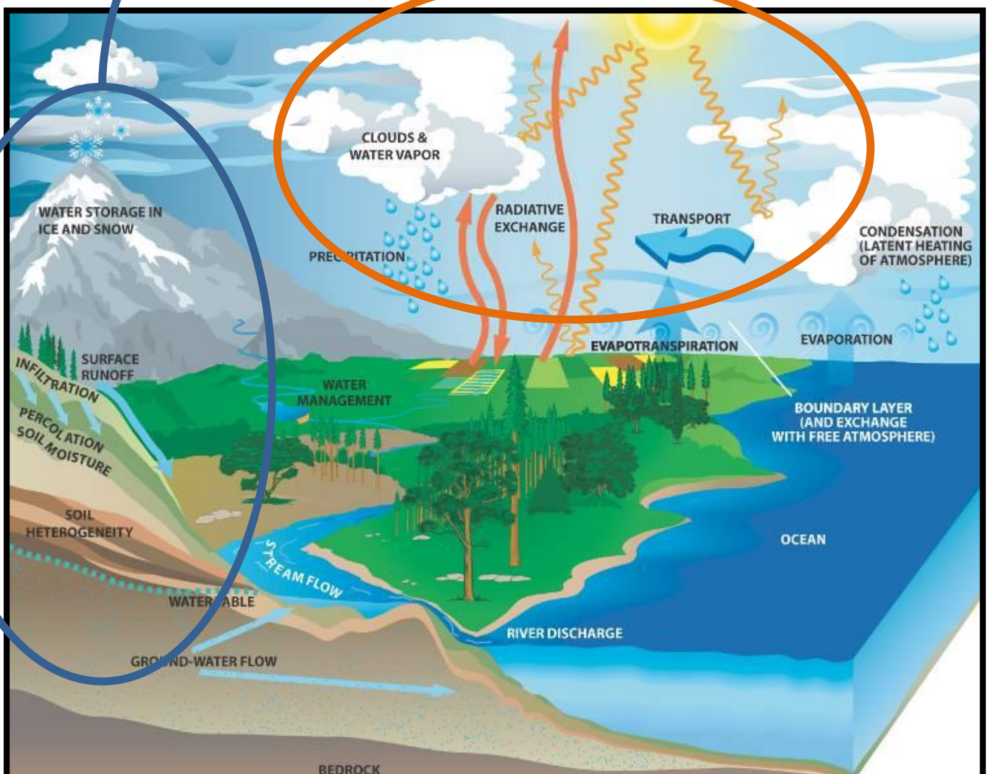
Index	Pattern
Nino 3.4	East Central Tropical Pacific SST
Nino 1+2	Extreme Eastern Tropical Pacific SST
Nino 3	Eastern Tropical Pacific SST
Nino 4	Central Tropical Pacific SST
AMO	Atlantic Multidecadal Oscillation
NAO	North Atlantic Oscillation
PDO	Pacific Decadal Oscillation
PNA	Pacific North American Index
SOI	Southern Oscillation Index
MEI	Multivariate ENSO index
WP	Western Pacific Index
TNA	Tropical Northern Atlantic Index

Motivation

Opportunities for prediction

hydrological predictability (land)

meteorological predictability (climate)



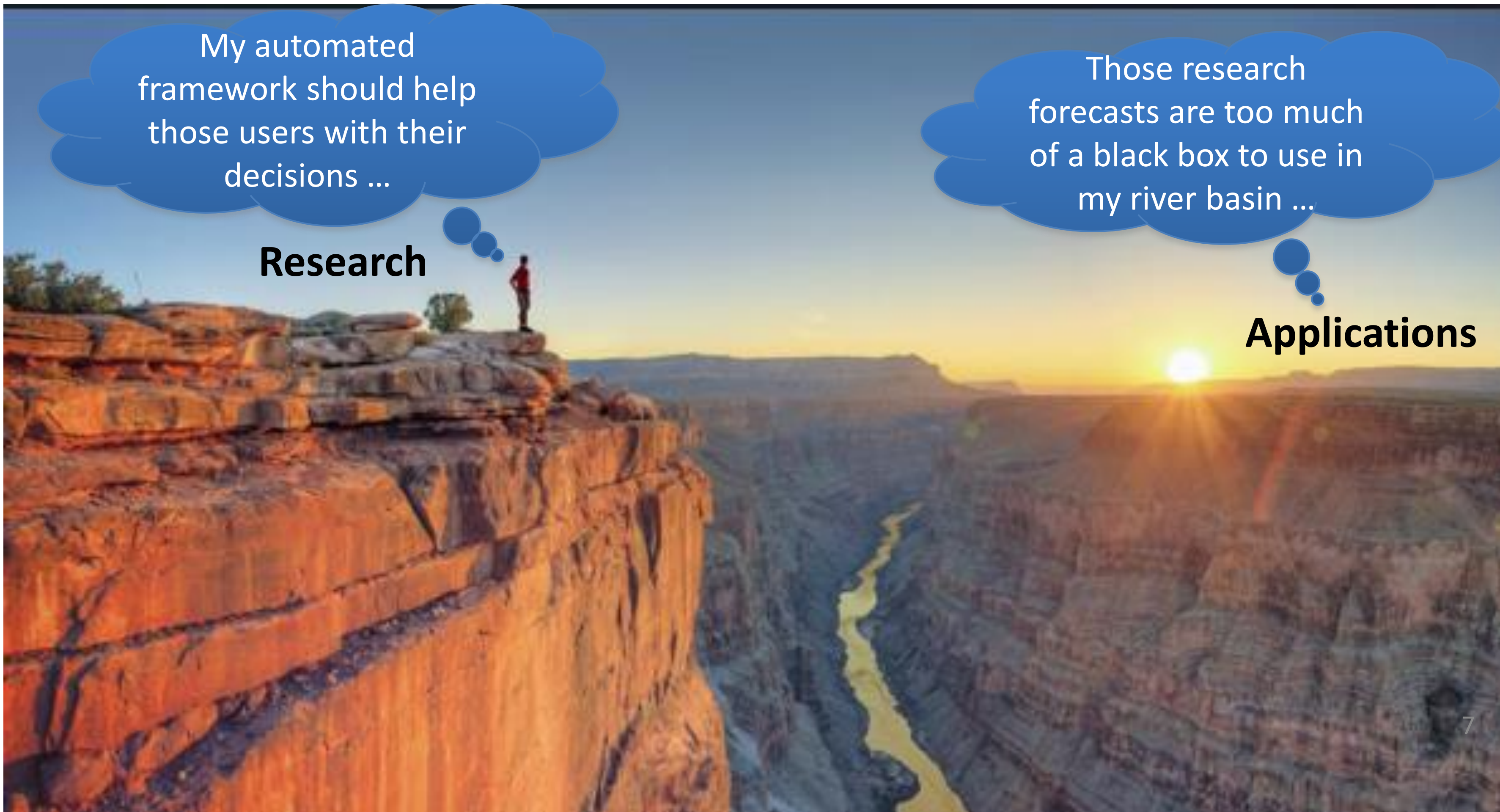
Water Cycle (from NASA)

Can we reconcile advances in both to improve the predictability of seasonal streamflow?

Goals

Use hindcasting to help inform real-time forecasting through:

- ❑ Identify potential benefits of using **more complex methods**
- ❑ Assessing new methods that use both **climate and land information**
- ❑ Demonstrating an **over-the-loop paradigm** (fully-automated forecast test-bed)



This study: systematic inter-comparison of methods

Benchmark Forecasts

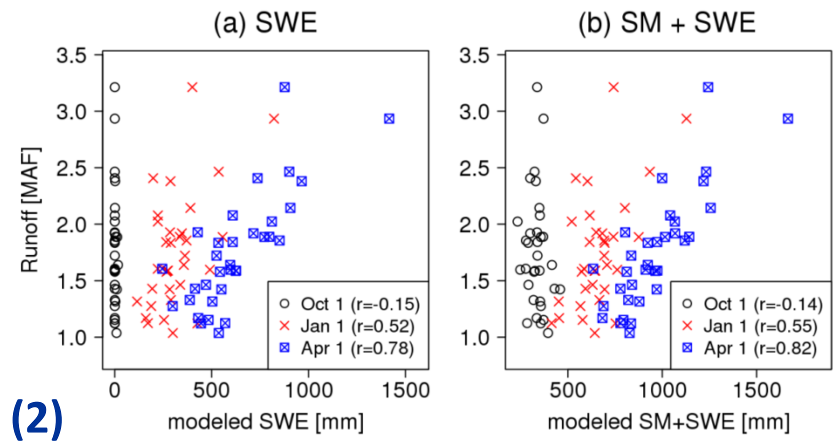
1. Dynamical: ensemble streamflow prediction (**ESP, BC-ESP**)
2. Statistical: regression on *in situ* information, Initial Hydrologic Conditions (**Stat. IHC**)

Statistical methods with climate info

3. Statistical with standard climate indices (**Stat. Indices**)
4. Statistical with custom indices (**Stat. CFSR**)

Hybrid/hierarchical methods

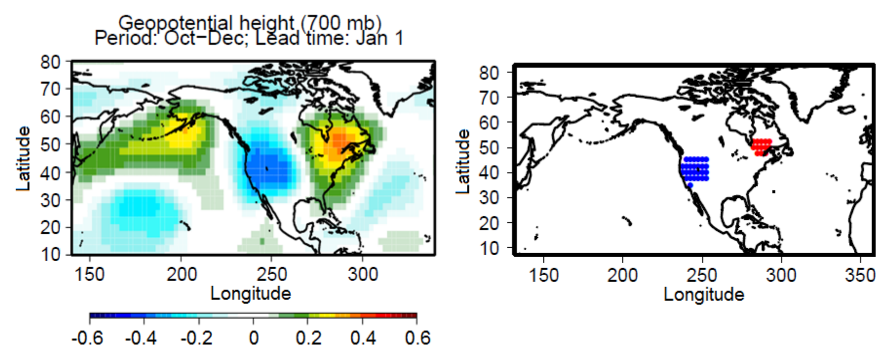
5. Purely statistical hybrid (**Stat. Ind+IHC**)
6. Purely statistical hybrid (**Stat. CFSR+IHC**)
7. Sequential IHC Climate-Error Regression, (**SICER**)
8. Trace weighting scheme, weighting ensembles based on climate info (**TWS**)
9. Equal weighting ensembles with climate indices (**EWE**)
10. Combine best climate (Stat. Indices or Stat. CFSR) with best hydrologic state (BC-ESP or Stat. IHC) based on RMSE (**RWE**)
11. Same as 10, but use Bayesian Model Averaging (**BMA**)
12. Same as 10, but use Quantile Model Averaging (**QMA**)



(2)

(4)

- Develop correlation maps between atmospheric/oceanic variables & runoff.
- Identify areas with maximum (positive) and minimum (negative) correlations.
- Compute predictor indices.



Predictor indices = Mean[+] - Mean[-]

Study sites

Five basins upstream reservoirs in the U.S. Pacific Northwest

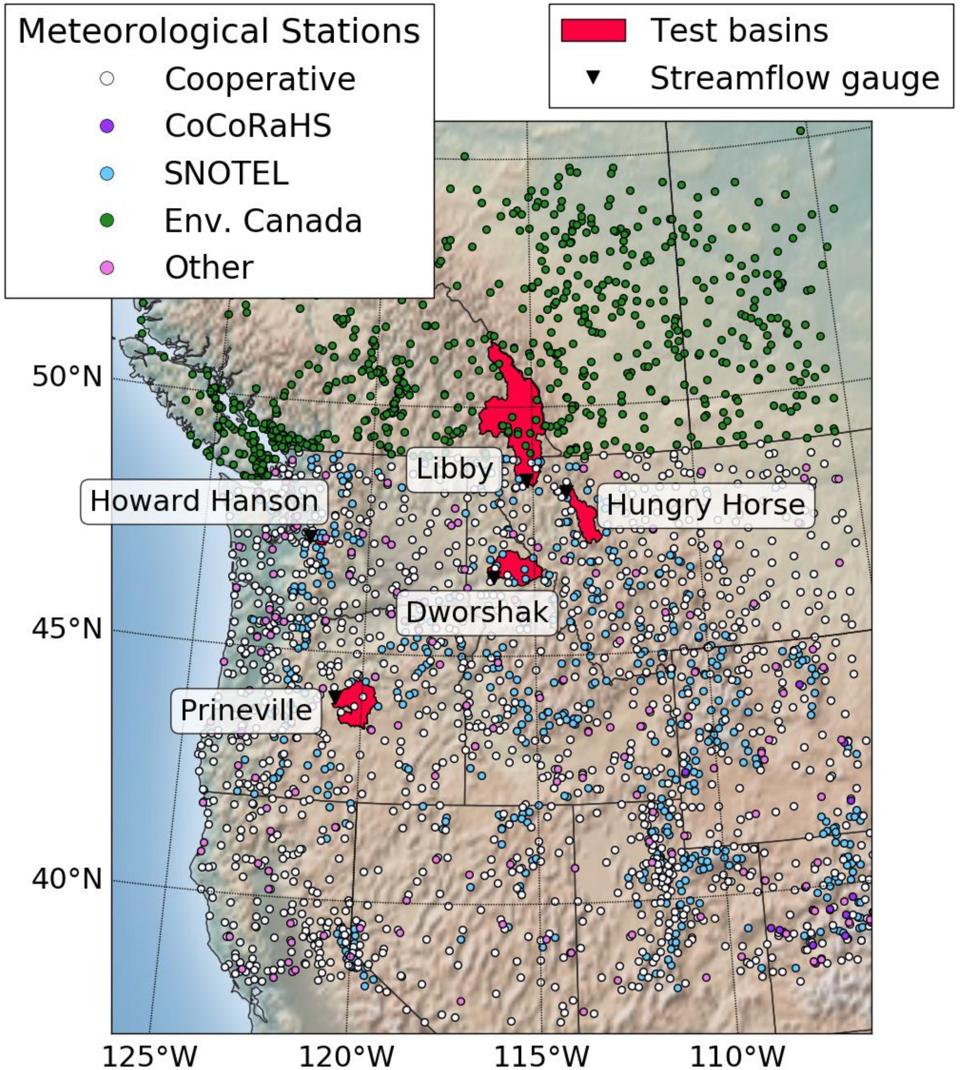
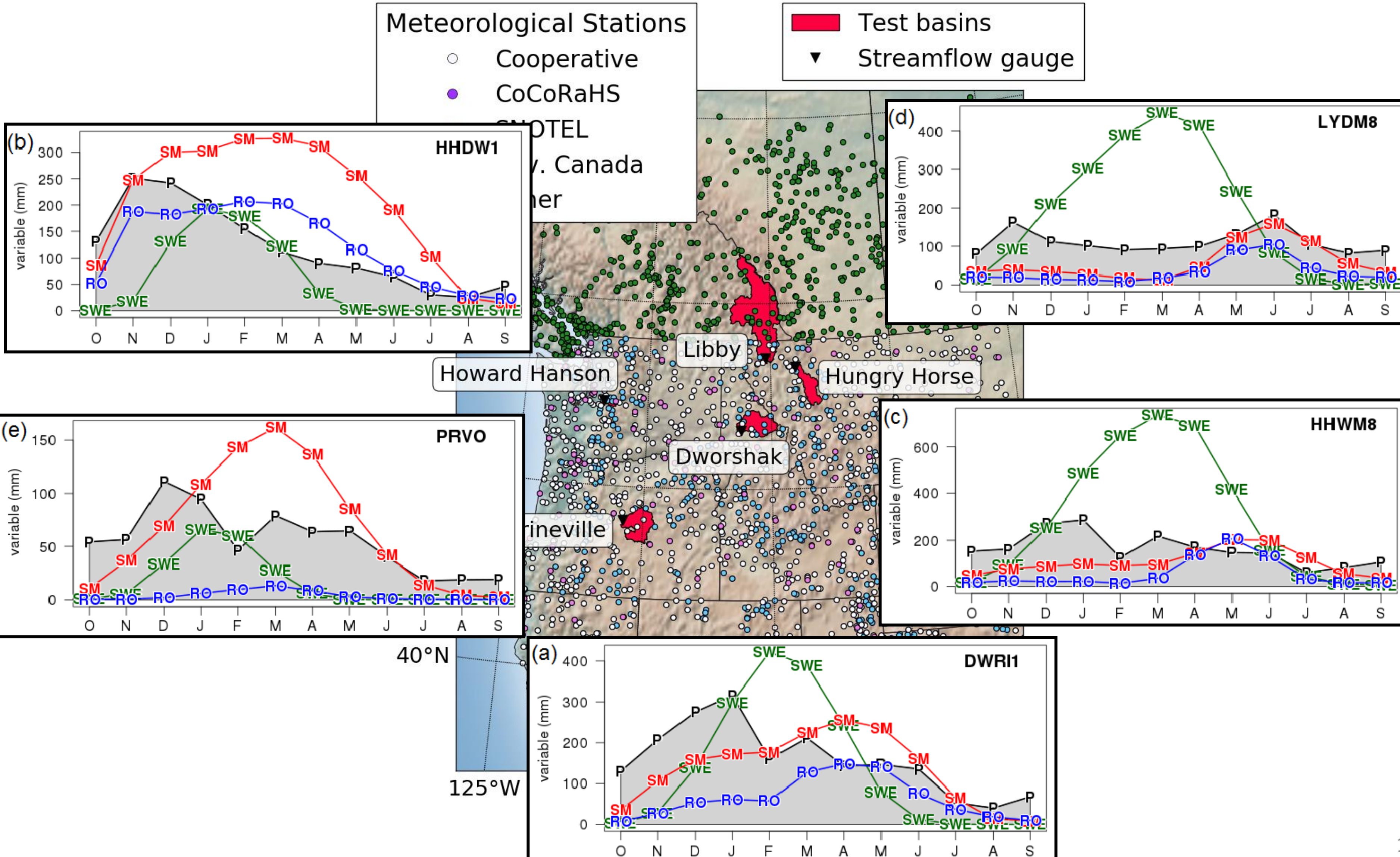


Figure by Elizabeth Clark

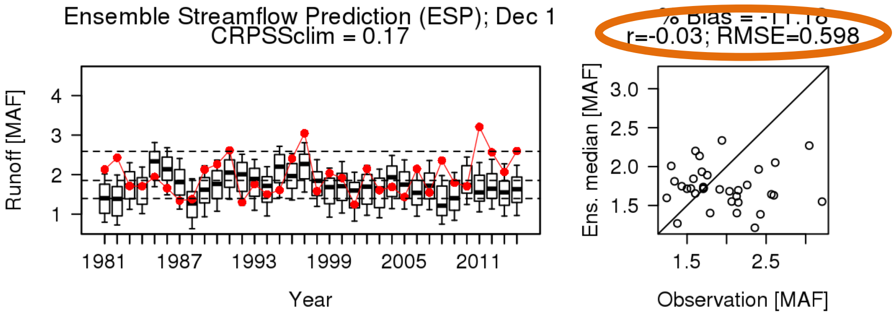
Study sites

Five basins upstream reservoirs in the U.S. Pacific Northwest

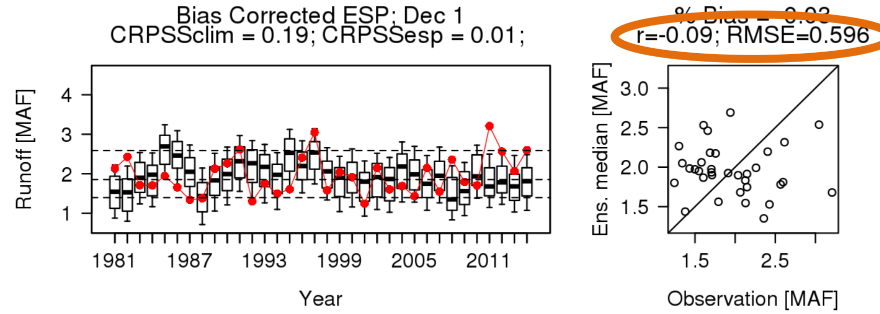


What added value does climate information bring?

Example: Hungry Horse



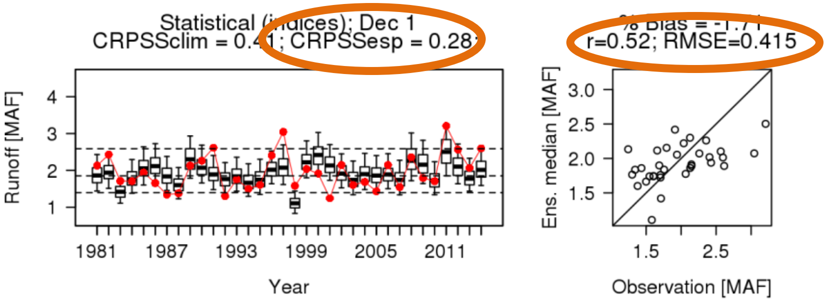
Raw ESP



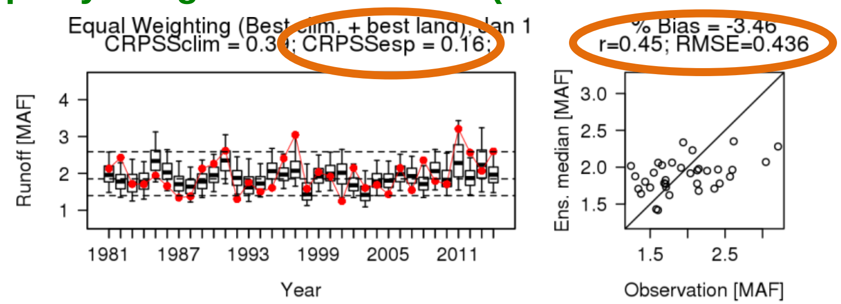
December 1

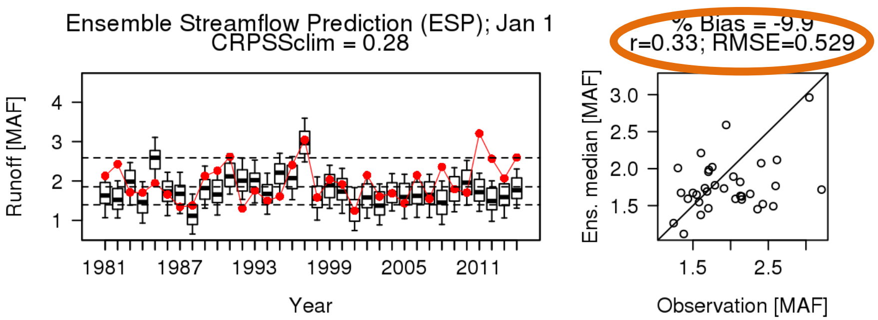
Bias corrected ESP

Statistical with indices

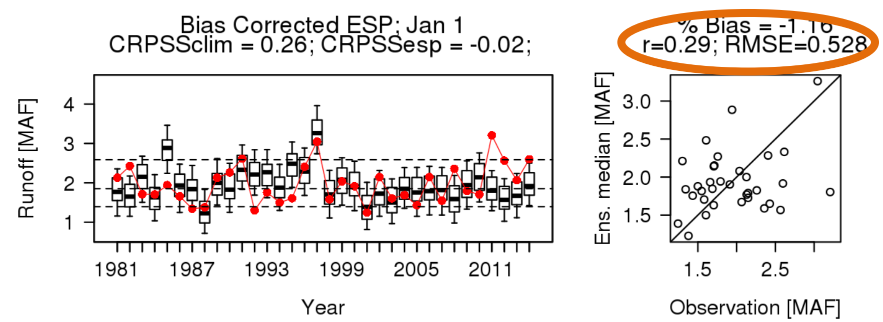


Equally Weighted ensembles (best clim. + best land)





Raw ESP

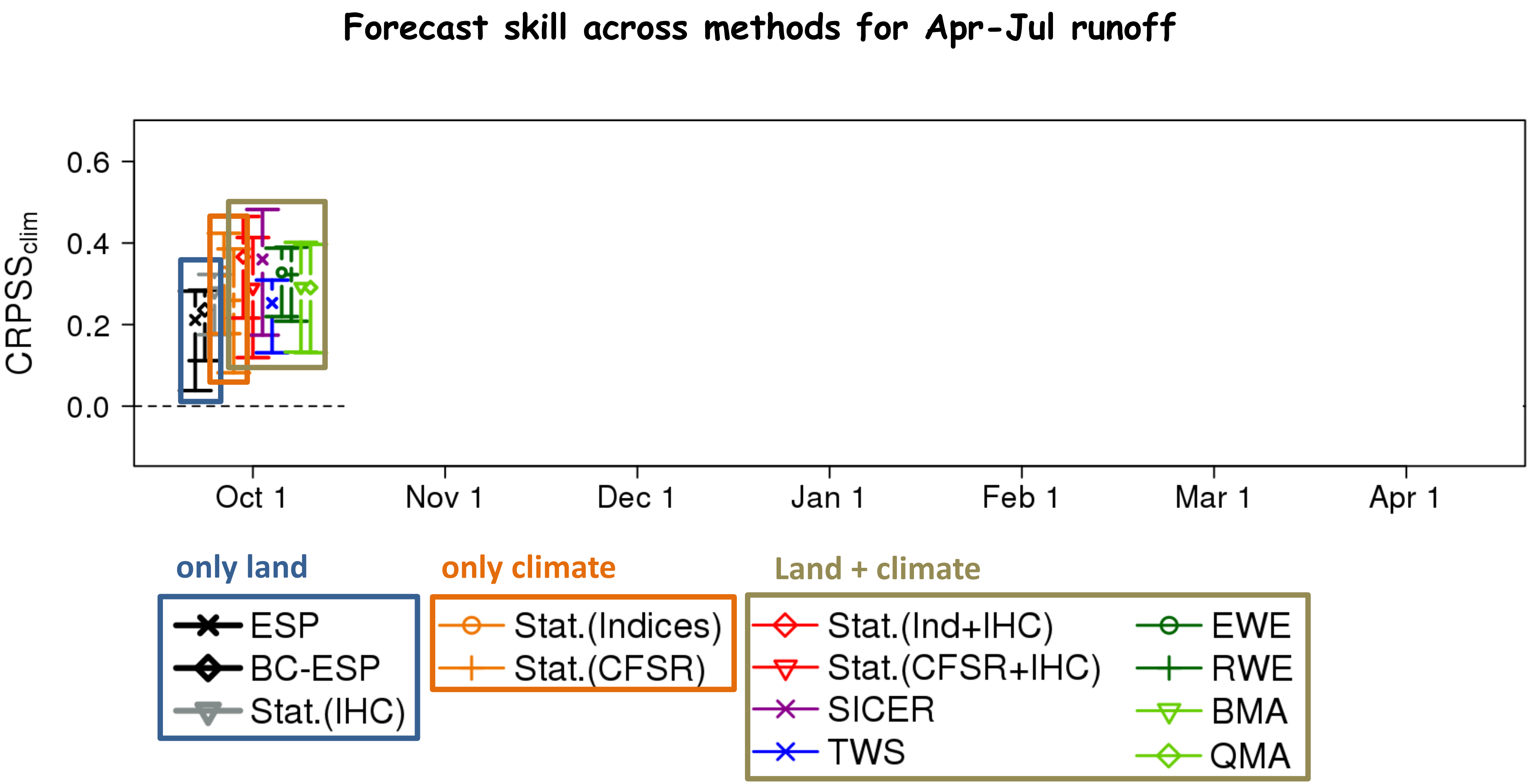


January 1

Bias corrected ESP

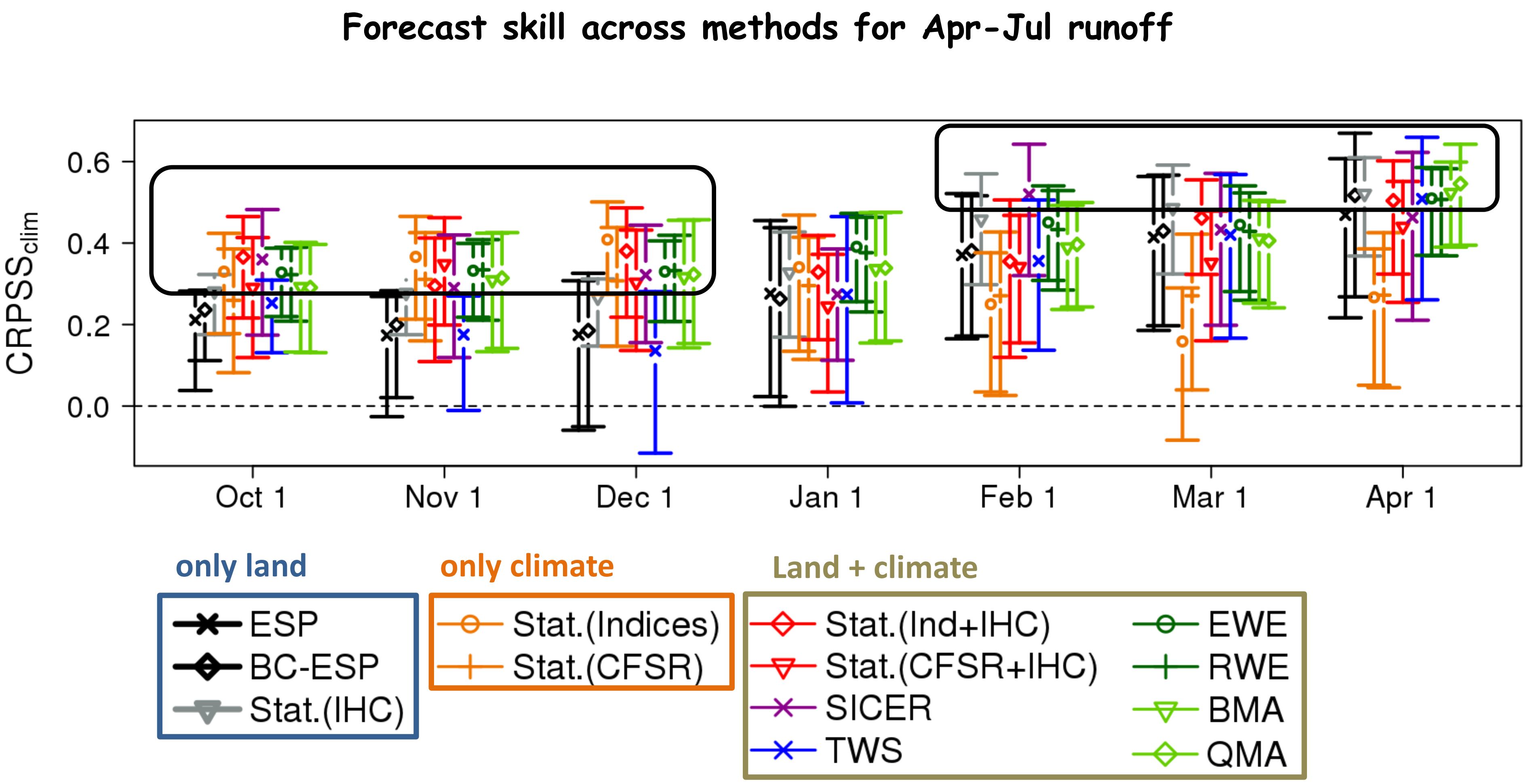
What added value does climate information bring?

Example: Hungry Horse



Example: Hungry Horse

What added value does climate information bring?



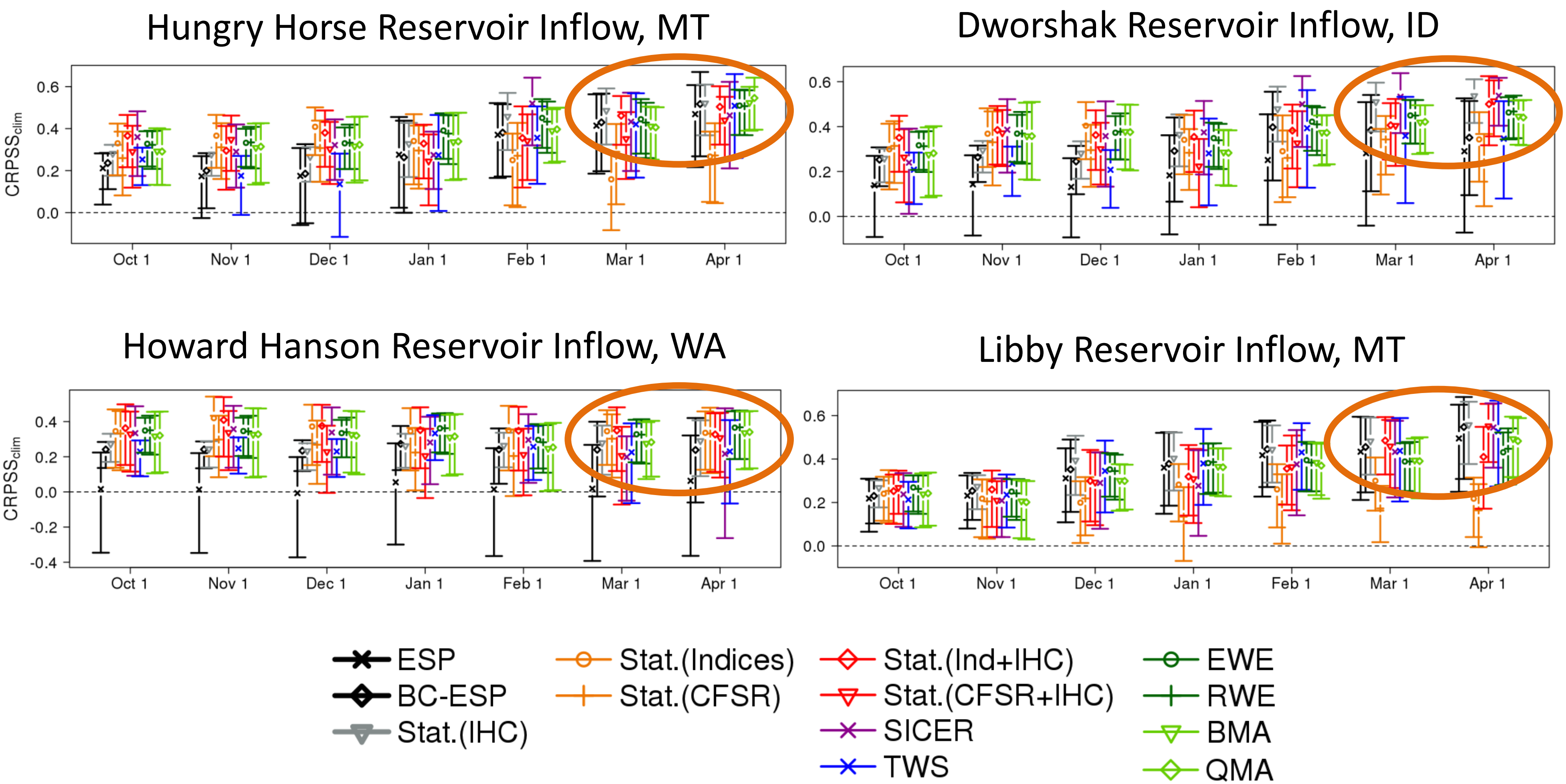
- Before January 1: we can beat benchmark only using climate info.
- Later initialization: An IHC regression can be as skillful as ESP.
- Hybrid approaches appear strongest overall

Outline: 1. Introduction 2. Approach **3. Results** 4. Summary

U.S. Pacific Northwest

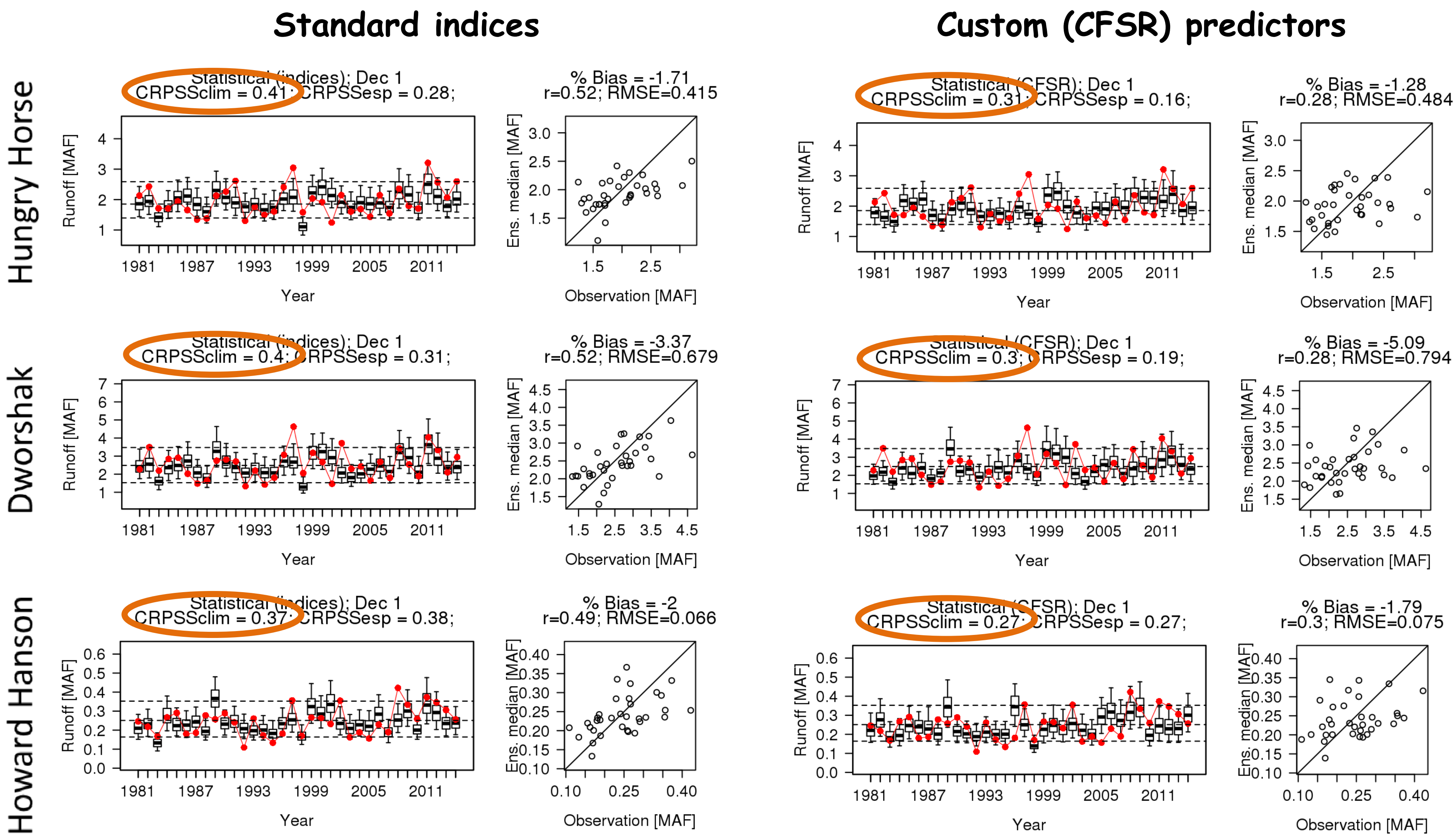
What added value does climate information bring?

Forecast skill across methods for Apr-Jul runoff



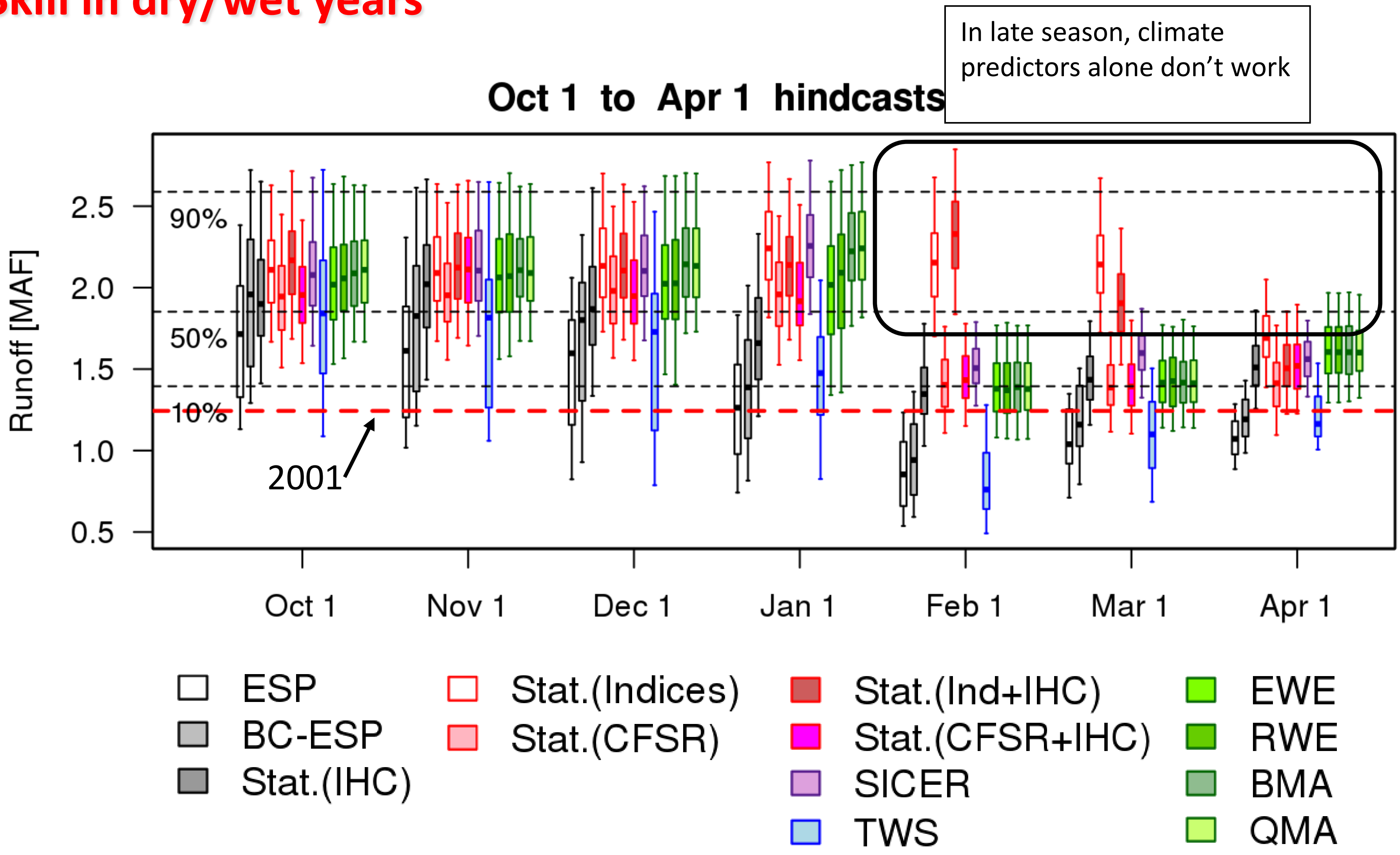
- ❑ Climate info relevant in early initializations, and land info dominates after January 1.
- ❑ At later initializations, similar or better skill can be obtained with simpler methods.

Standard indices or custom (reanalysis) predictors?



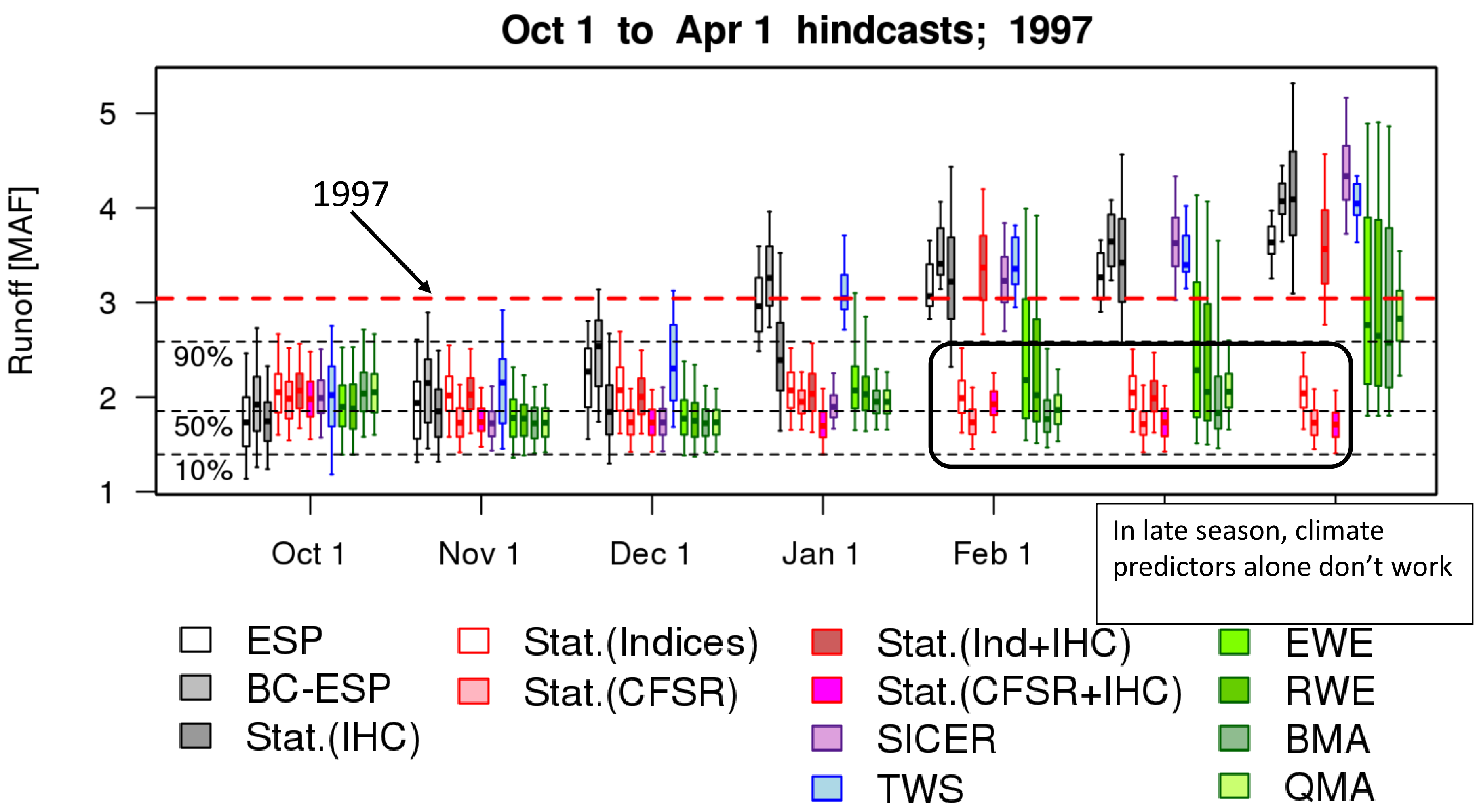
- Statistical models with standard indices outperform those using custom indices

Skill in dry/wet years



What methods do better in dry years?

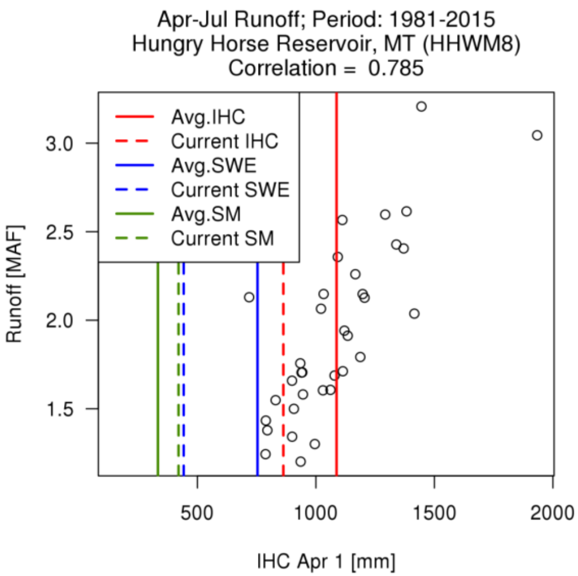
Skill in dry/wet years

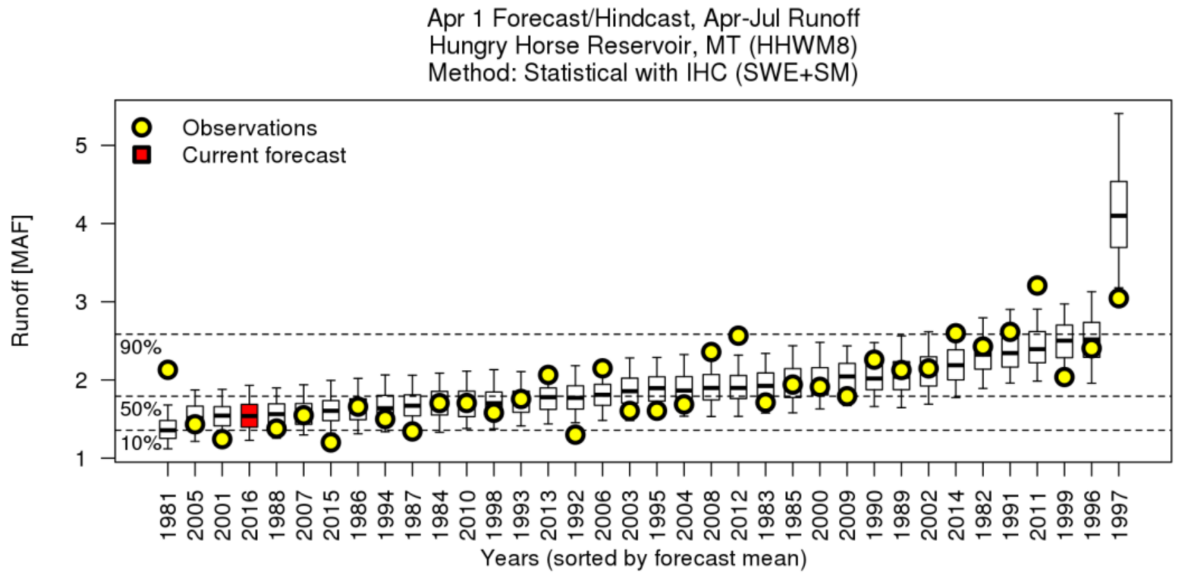


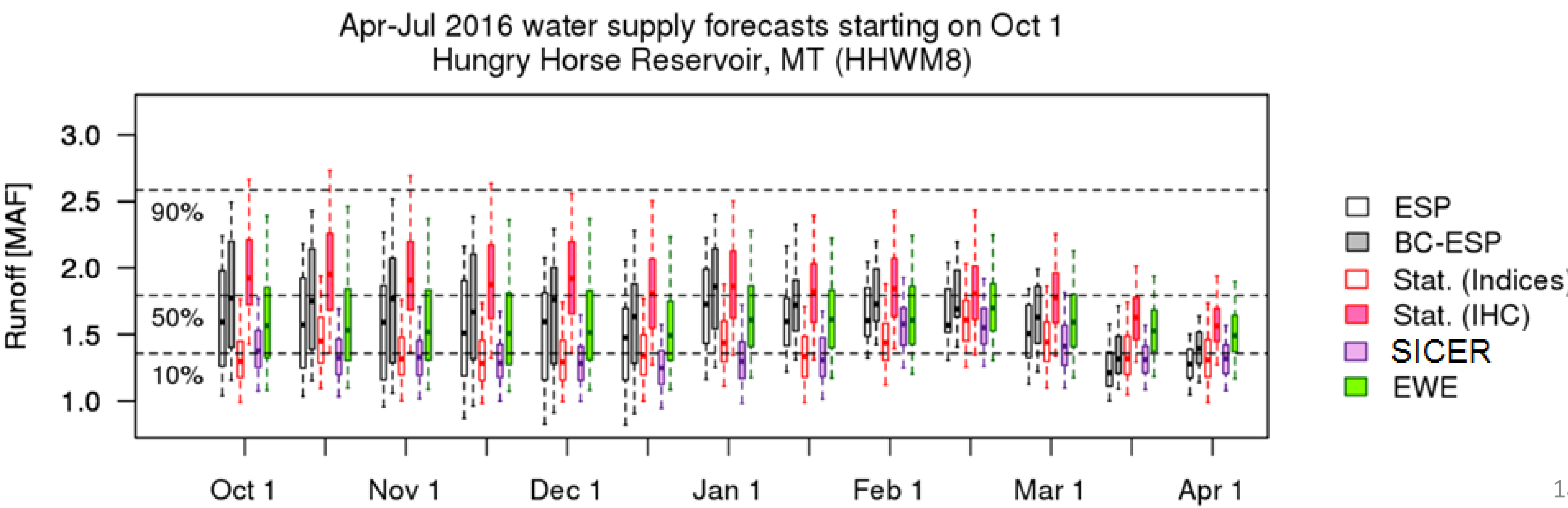
What methods do better in wet years?

WY 2016: initialized April 1

Apr-Jul runoff
Hungry Horse







Outline: 1. Introduction 2. Approach **3. Results** 4. Summary

Website: www.ral.ucar.edu/staff/wood/case_studies_wr/

WR Case Study Watersheds

A small set of watersheds is being implemented for assessment of reservoir inflow forecasts. The watersheds are relatively unimpaired 'headwater-ish' basins that provide inflows for reservoirs managed by collaborators, including the federal water agencies (US Army Corps of Engineers and Bureau of Reclamation).

Regions		
14 UCO	**17 PN**	**18 CA**
TBA	HHWM8 Hungry Horse Res. Inflow DWRI1 Dworshak Res. Inflow HHDW1 Howard Hanson Res. Inflow PRVO Prineville Res. Inflow LYDM8 Libby Res. Inflow	TBA

A larger set of forecast demonstration watersheds that will have forecasts but not be the focus of reservoir manager interactions is shown in a Hydro Case Study Watersheds page. Those case studies were selected from the much larger CONUS-wide dataset of Newman et al. (2015) for use in assessing hydroclimate forecasting data and methods.

These basins are considered relatively unimpaired (part of the HCDN network) but also have water management significance -- eg, provide inflow for reservoirs -- or were included for their relevance to other studies. The basin subsets can change given interest from collaborators.

Seasonal WS Forecasts | Current Conditions | Basin Map | Calibration | Location Map | Skill Information

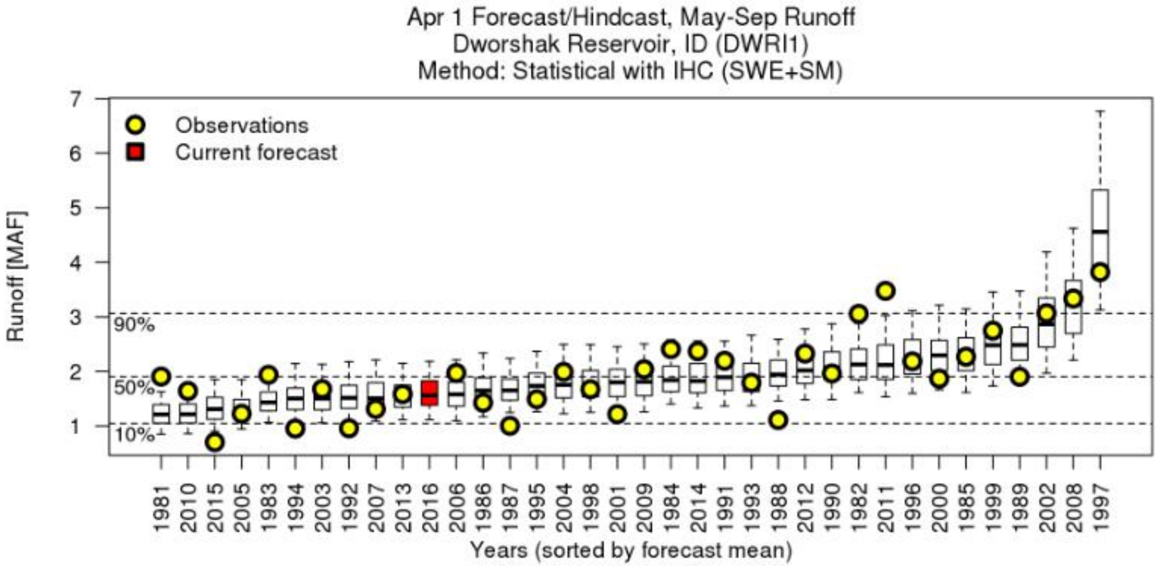
Location: DWRI1

Current water supply forecasts for different runoff periods. The forecasts are represented in several ways:
-- The current forecast is plotted along with hindcasts from prior years (using the same methodology), and their verifying observations. The climatological distribution is also shown by the horizontal dashed lines across the plot.
-- PDFs for several forecasting approaches are shown, compared to their historical distributions for 1980-2010.

-- Scatter plots of the forecast distributions for all years, versus observations, for the different methods.

Data files are available for the different forecasts below the plots for each forecast period.

May-September | April-July | April-September | Back to Top

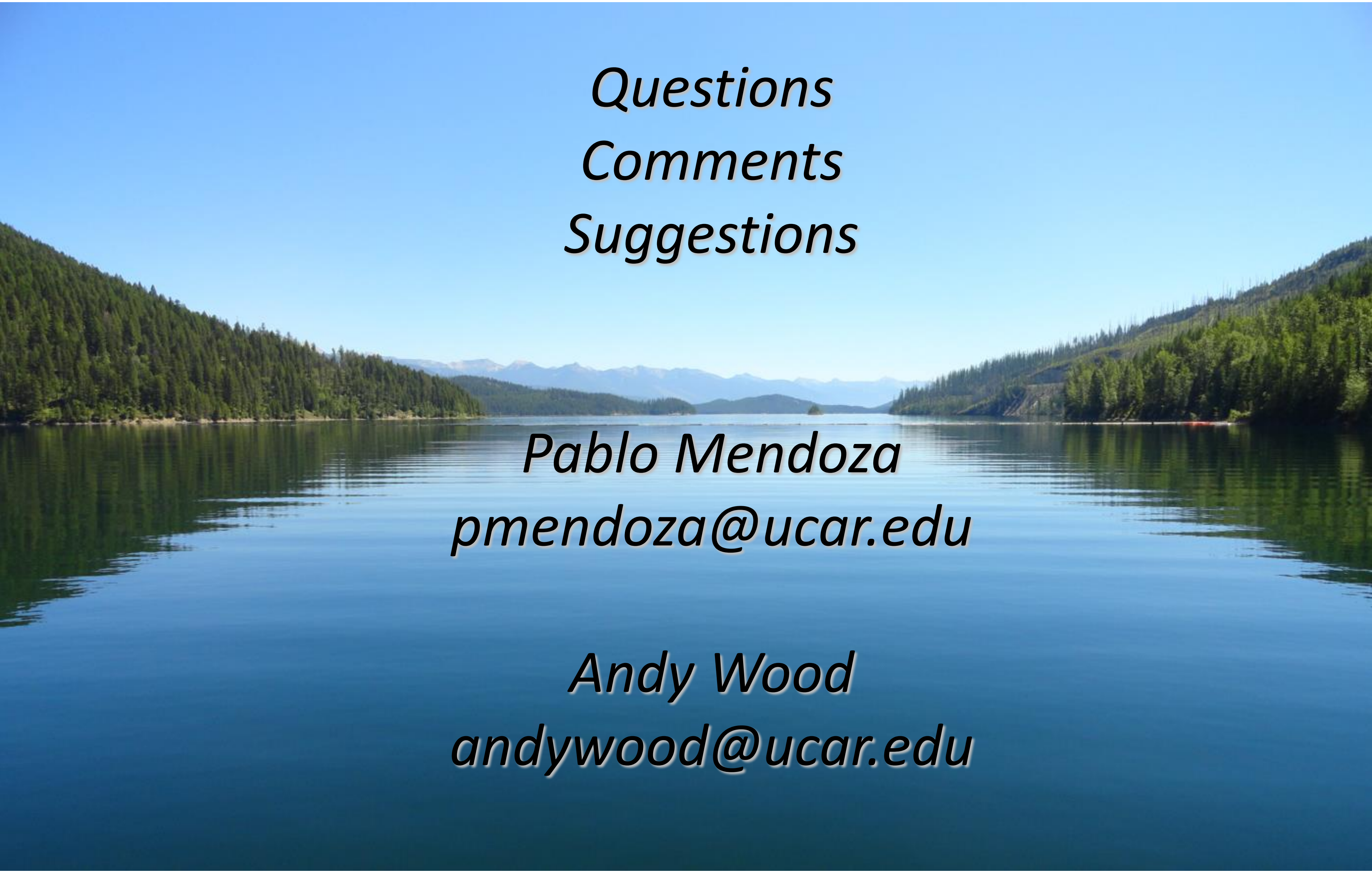


Summary and Future work

- **An inter-comparison framework has been developed including statistical, dynamical and hybrid approaches.**
- **Findings**
  - Hybrid combinations of climate and watershed predictability provide gains.
  - Custom (reanalysis) indices do not outperform standard climate indices.
  - Trace-weighting works only if ESP works.
- **Real-time WSFs being operationalized (in process)**
  - Real-time system IHCs and ESPs coming online with new gridded ensemble forcing.
  - Interactions with Boise Area Office (Reclamation) helping shape products.
  - Other water management groups interested (e.g., BPA, Tacoma Power, Idaho Power) as well as NWS (NWRFC, CNRFC).

Next Steps

- **Operationalize non-WSF predictands (1 month, 3 month)**
- **Ongoing diagnostics to understand forecast discrepancies**
- **Adding new basins for interested partners**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