Seasonal hydrologic forecasting
a proposed intercomparison experiment

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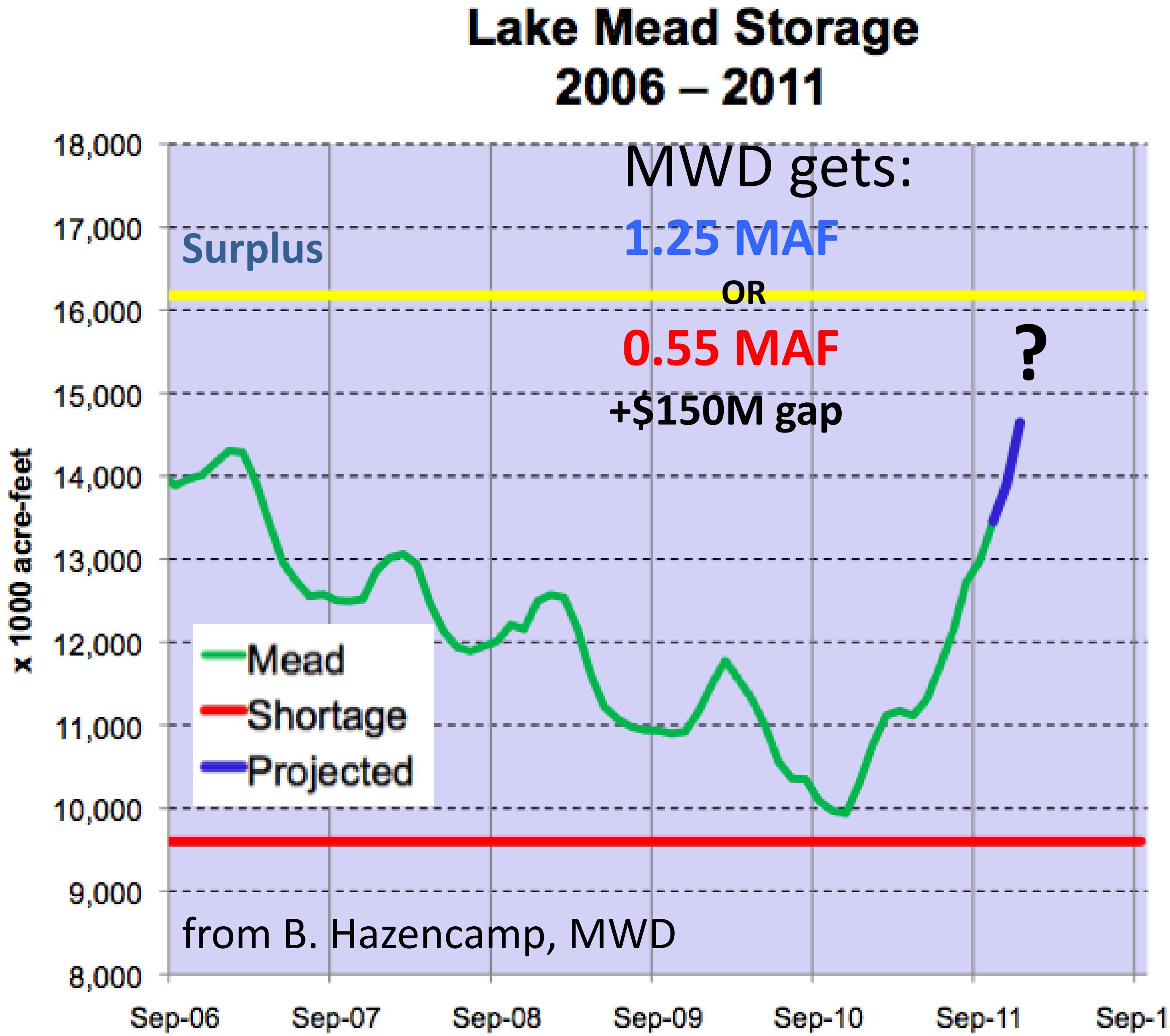
Motivation

- Seasonal hydroclimate forecasting for water management has tremendous societal value (economic, social)

Seasonal streamflow prediction is critical



One example:
Met. Water Dist. of S. California (MWD)

The urgency of understanding predictability

teleSUR Article Dec 8, 2014

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AGENDA | Human Rights Day | CIA Torture | Battling for Climate Justice | US Resists Police Racism

News > Latin America

Drought-Hit Sao Paulo Has Two Months of Water Left

A man looks at the cracked ground of Jaguari dam, part of the Cantareira reservoir in Sao Paulo state, showing record low water levels January 31, 2014. (Photo: Reuters) | Photo: Reuters

Published 8 December 2014

The emergency reserves should last for two months, but water use is also expected to increase during the holiday season.

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- In the US and likely other countries, seasonal forecasting methods that may be quite ad hoc have become entrenched, changing little in decades
  - based mostly on initial hydrologic conditions
  - may be partly subjective, non-repeatable, impossible to verify

Simple Statistical Forecasting

Trial Lake SNOTEL

Sample Equation for April 1 forecast of April-July Flow:

April-July volume Weber @ Oakley =

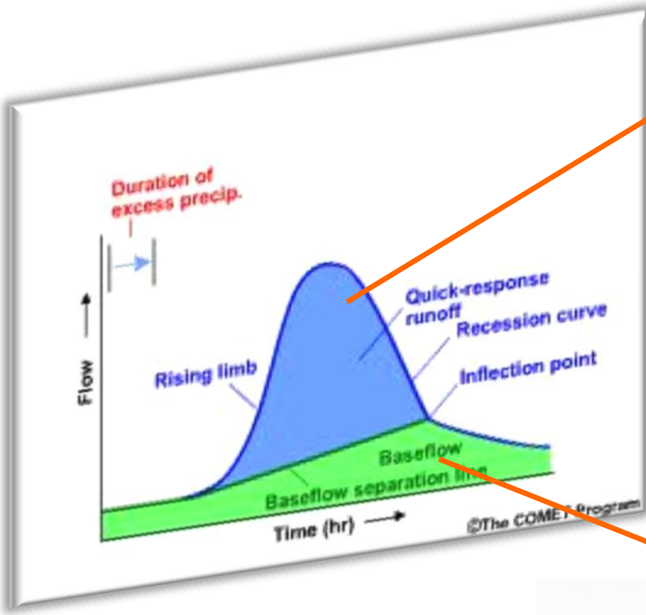
+ 3.50 * Apr 1st Smith & Morehouse (SMMU1) Snow Water Equivalent
+ 1.66 * Apr 1st Trial Lake (TRLU1) Snow Water Equivalent
+ 2.40 * Apr 1st Chalk Creek #1 (CHCU1) Snow Water Equivalent
- 28.27

Model Based Forecasting

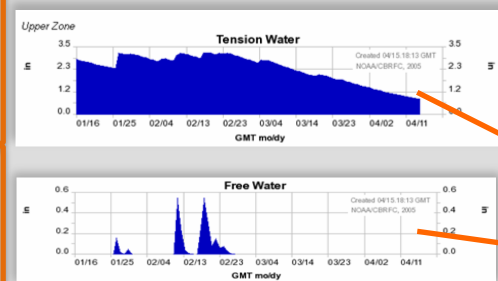
End-to-End Operational Forecast Process

Data Preparation → **Modeling** → Dissemination

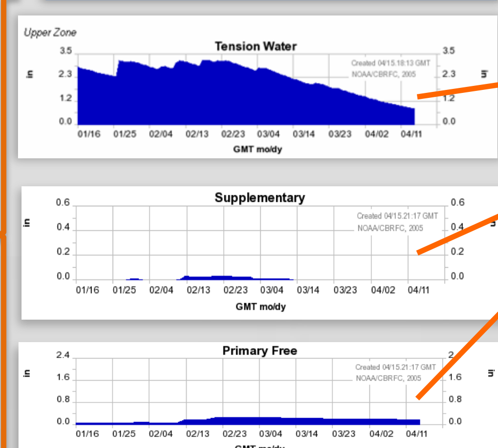
Temperature index model for simulating snowpack accumulation and melt ➔

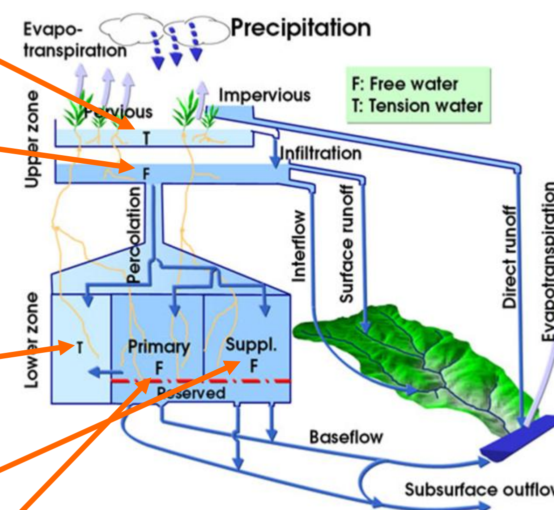


Observed Hydrology



Simulation and Analysis





Sacramento Soil Moisture Accounting Model

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- Over the past decades, many advances could benefit seasonal streamflow prediction:
  - climate forecasting, supercomputing, land surface modeling, statistical methods, real-time availability of monitoring data (eg, snow pillows)
  - there is a need to demonstrate these advances for basins that national services find familiar to motivate upgrades
  - there is a need for transparency on methods

Need for community assessment of methods

It is sometimes difficult to tell if results from the literature

1) will work in your basins of interest
2) have been done correctly

WATER RESOURCES RESEARCH, VOL. 41, W10410, doi:10.1029/2004WR003467, 2005

A technique for incorporating large-scale climate information in basin-scale ensemble streamflow forecasts

Katrina Grantz[1] and Balaji Rajagopalan[2]
Department of Civil, Environmental and Architectural Engineering, University of Colorado, Boulder, Colorado, USA

Martyn Clark
Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder, Colorado, USA

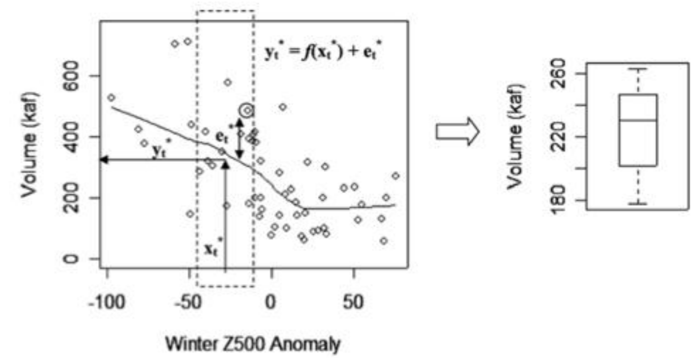
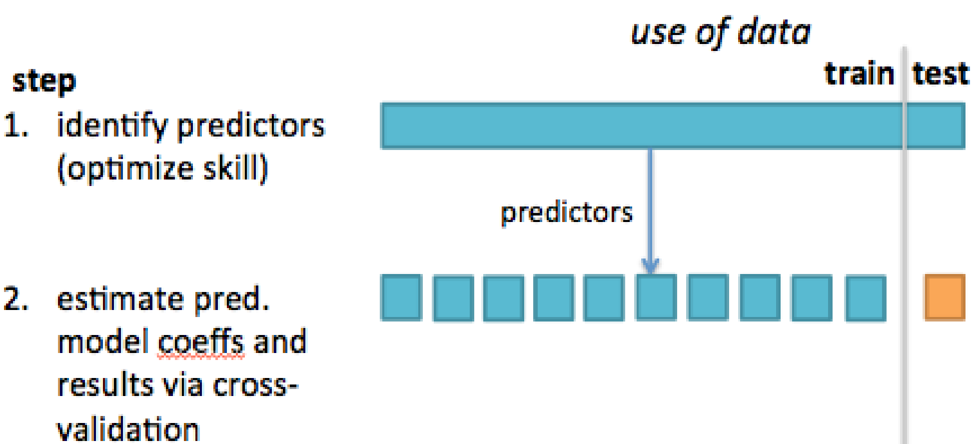
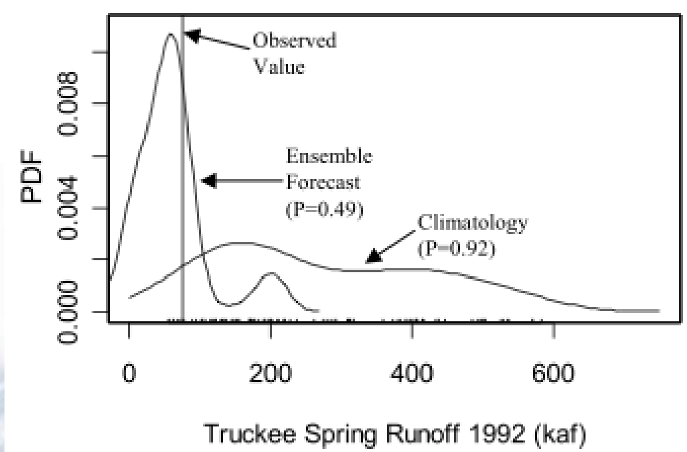


Figure 6. Residual resampling to obtain an ensemble forecast.





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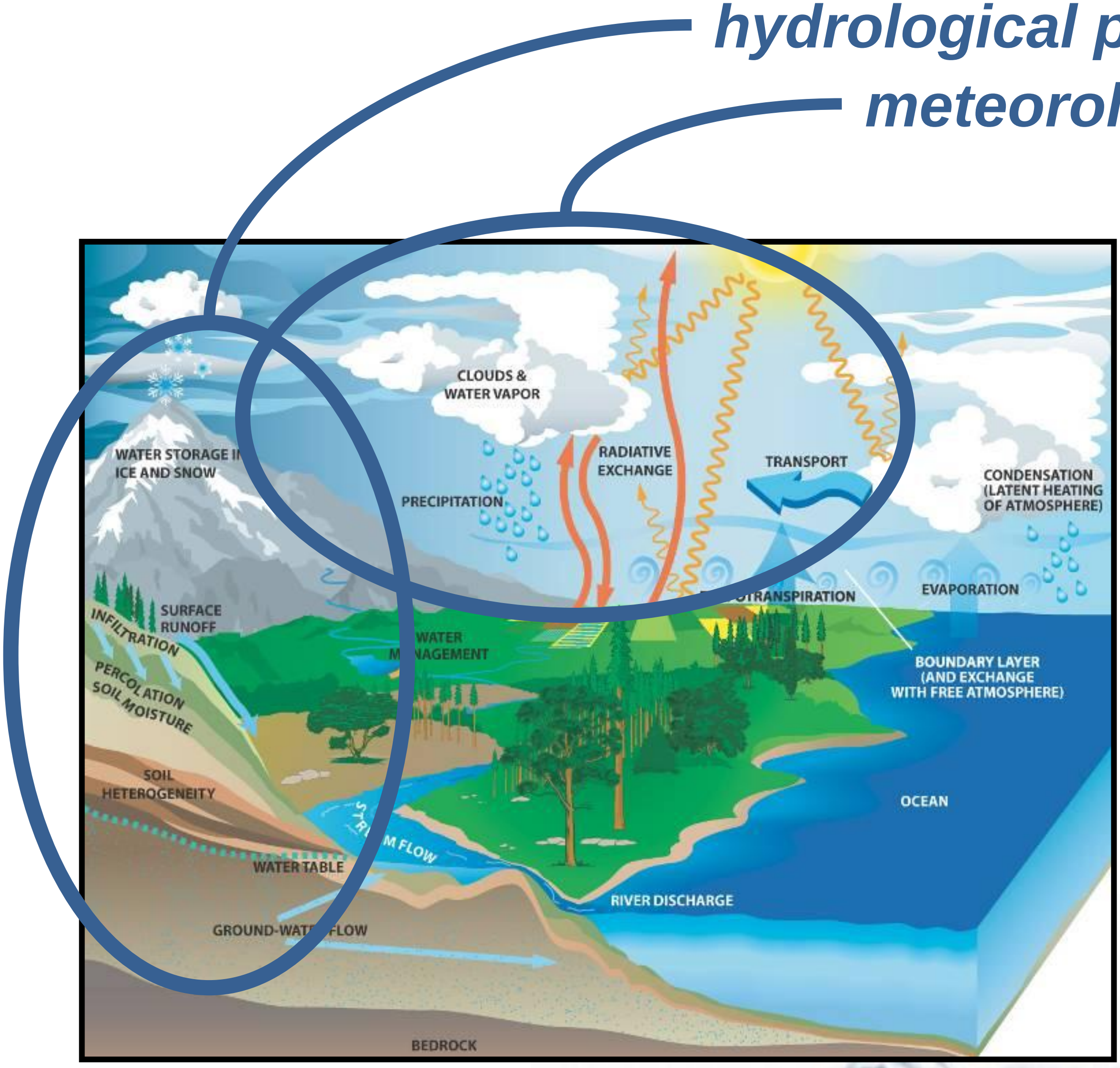
- An intercomparison experiment can lead to consensus on the broad outlines of a robust approach that synthesizes the learning of many researchers

hydrologic prediction science questions

hydrological predictability

meteorological predictability



Water Cycle (from NASA)

Hydrological Prediction: How well can we estimate catchment dynamics?

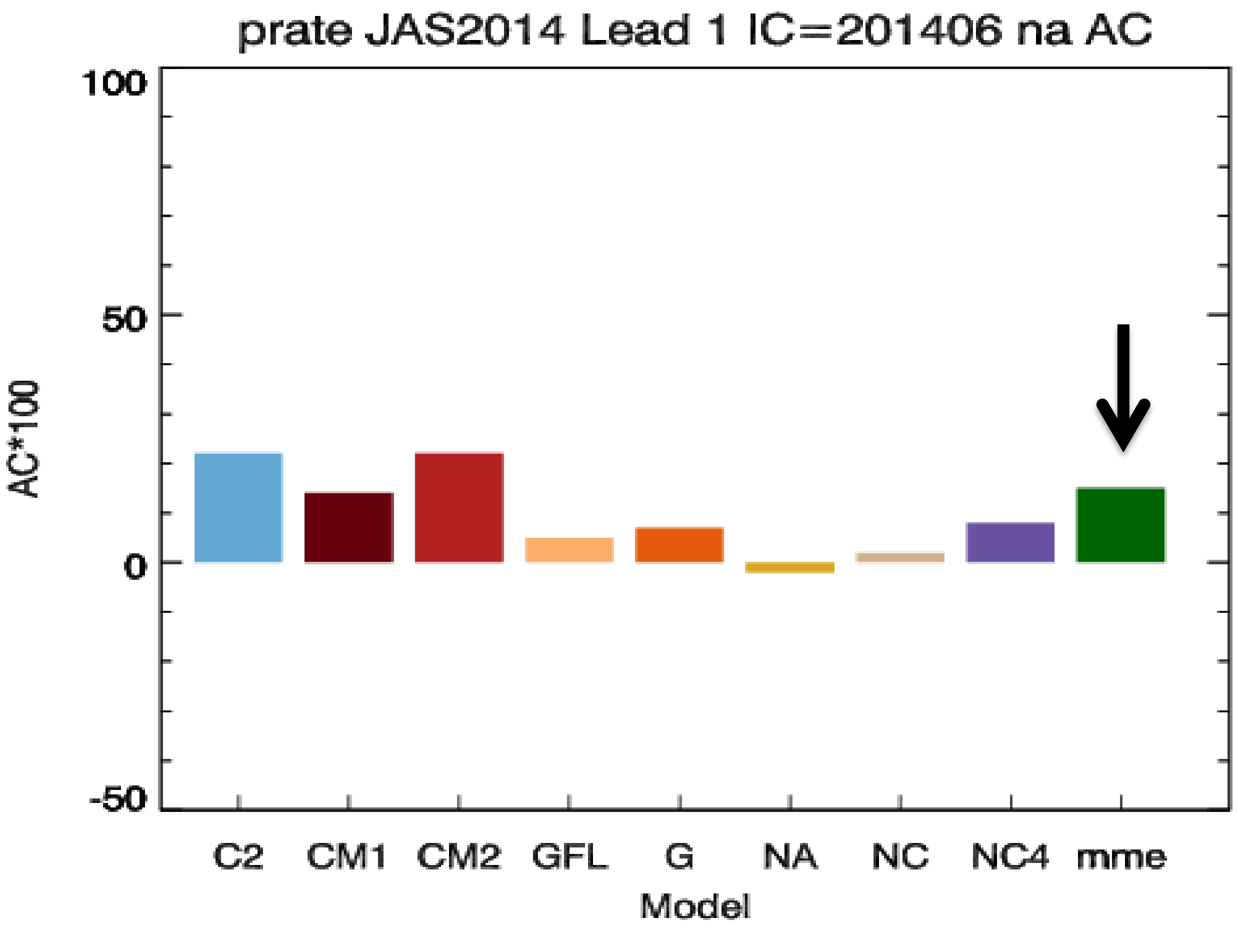
- Accuracy in precipitation and temperature estimates
- Fidelity of hydrology models – process/structure
- Effectiveness of hydrologic data assimilation methods

Atmospheric predictability: How well can we forecast the weather and climate?

Opportunities: How do these areas influence variability informing different water applications?

Climate Models now have better skill: eg, NMME at NOAA

The NMME is the latest/greatest effort at climate prediction from N.A.:
- models vary in skill each month, and by region



Efficiency – Complexity Tradeoff

- **A number of forecasting centers around the world have offered seasonal streamflow predictions for decades (over 80 yrs in the US, for instance).**
  - Other countries/agencies are interested in starting such services.
- **The approaches span a wide range of data requirements & complexity. From simplest to most complex (light to heavy data lift):**
  a. regression of flow on in situ obs (rainfall, SWE, flow)
     - 'regression' = regressive technique, ie PCR, MLR, etc.
  b. the same but with teleconnection indices included as predictors
  c. the same but with custom climate state predictors (eg EOFs of SST) or climate forecasts
  d. land model based ensemble simulation (eg ESP or HEPS) without climate forecast
     - possibly with short to medium range prediction embedded
  e. climate index (or custom index) weighted ESP
  f. climate forecast weighted ESP (eg using CFSv2 or NMME in the US)
  g. climate forecast downscaled outputs with weather generation for land model ESP/HEPS
     - from one land/climate model or multi-model; from simple land model to hyper-resolution
  h. d-g with statistical post-processing to correct model bias
  i. d-g with post-processing to correct bias and merge with other predictions (cf BOM approach)
  j. d-g with DA to correct land model errors (particularly with snow variables)
  k. d-g with both post-processing AND DA

simple statistical approaches can be viewed as benchmark for complex dynamical approaches

Using Hindcasting assessment

Case Study Basin Subset

- 50 watersheds (and growing), chosen for varying hydro-climates & regions, being relatively unimpaired, and supplying reservoir inflows

Predictability Project Case Study Watersheds

Home Info Links Contacts Disclaimer

The watersheds in the table below were selected from the 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. A minimum of two watersheds with such characteristics per region were sought, but in some cases (eg, for SRR), they were not found, and the locations were chosen based on the quality of the NCAR simulations. A few additional basins were included for their relevance to other studies.

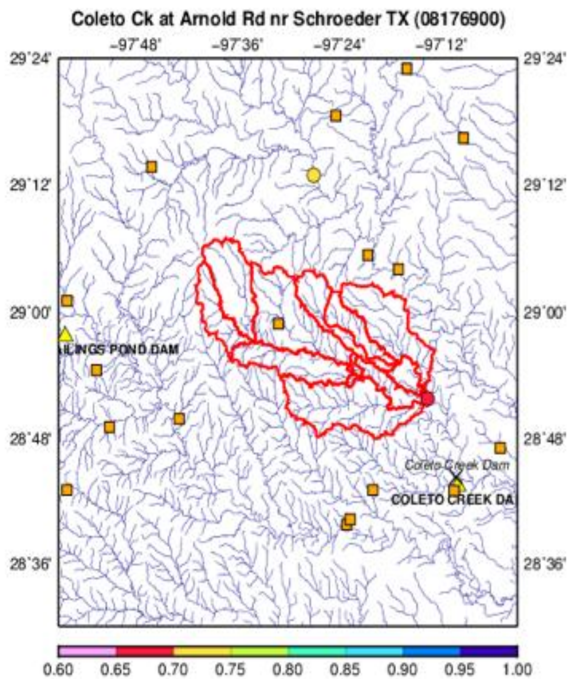
Regions

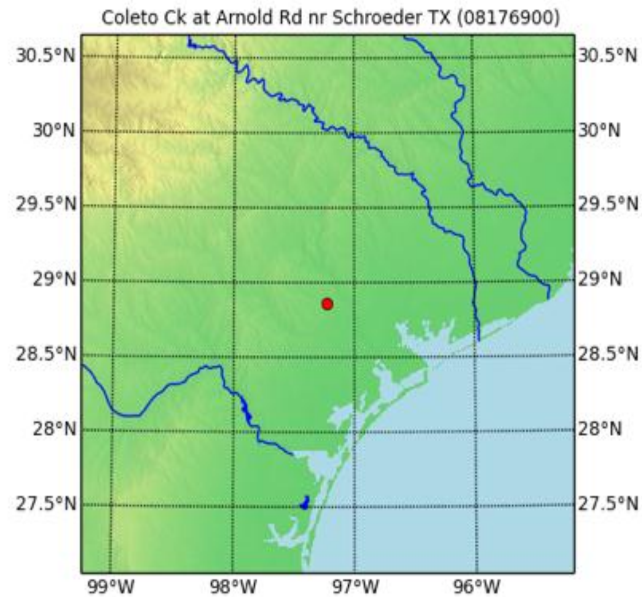
01 NE	02 MA	03 SAG	04 GL	05 OH	06 TN	07 UMS	08 LMS	09 SRR
187300 013500	413500 414500 415000 591400 606500	371500 178400 177000	057800 124000	340800 164000 285000	455500 504000	593900 507600	362587 376000	057000 129115
10 MO	**11 ARW**	**12 TXG**	**13 RG**	**14 UCO**	**15 LCO**	**16 GB**	**17 PN**	**18 CA**
468250 224000	340300 226500	176900 070200	324000 380500	107000 223000 352900 081600	508300 430500	234500 343500	154500 308990 025700 056500 158790	176400 480390

A second, smaller set of watersheds is being considered that are not from the HCDN/Newman dataset but from basins forecasted by the NWS River Forecast Centers and managed by the federal water agencies. These will serve as a focus for interaction with reservoir managers from the US Army Corps of Engineers and the US Bureau of Reclamation. These basins are also relatively unimpaired and generate inflows for several important reservoirs in the western US.

Description

Watershed Maps include:
outlets (circle, color = calibration NSE), reservoirs (triangle,X), SNOTELs (star), met stations (square).





http://www.ral.ucar.edu/staff/wood/case_studies/

Case Study Basin Water Resources Subset

- 4-8 watersheds (in dev.), chosen for giving insight on water resources operations (ie headwater-ish basins providing major res. inflows)
- Discuss/Evaluate with reservoir management personnel

Forecast Demo Project

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 are also forecasted by the NWS River Forecast Centers and managed by the federal water agencies. These will serve as a focus for interaction with reservoir managers from the US Army Corps of Engineers and the US Bureau of Reclamation. These basins are also relatively unimpaired and generate inflows for several important reservoirs in the western US.

Regions		
14 UCO	17 PN	18 CA
TBA	HHWM8 DWRI1 HHDW1 LYDM8	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.

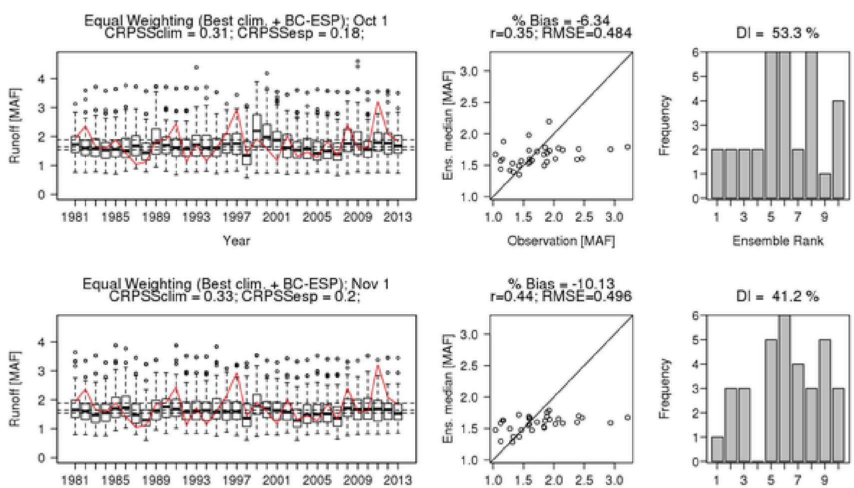
Seasonal WSF Hindcasts | Basin Map | Calibration | Location Map

Water supply forecasts (April-September) are displayed below for a series of hindcast dates from 1981-2010, initialized on the first day of each month from the beginning of the water year through May 1. These forecasts represent the best current results from a range of range of alternative prediction approaches that were assessed, including raw ESP, bias-corrected ESP, ESP with trace weighting, and statistical prediction via stepwise MLR based on simulated watershed moisture states (SWE and soil moisture, SM) and climate system predictors derived from the CFS reanalysis and reforecast analysis (eg, basin-specific indexes derived from variables such as SST and geopotential heights). All statistical prediction equations (including combinations of multiple forecasts such as ESP and a statistical prediction) were fully cross-validated (via leave-one-out), and the climate system predictors (ie, which form inputs to a prediction equations) were also cross-validated.

Raw ESP forecasts are provided below as a baseline (approximately representing the NWS method).

The plots show timeseries of the predicted distributions on the left, compared to observed WSF runoff (red line) and scatter plots of the forecast ensemble median on the right. Plot data can be downloaded from links to the right of each plot.

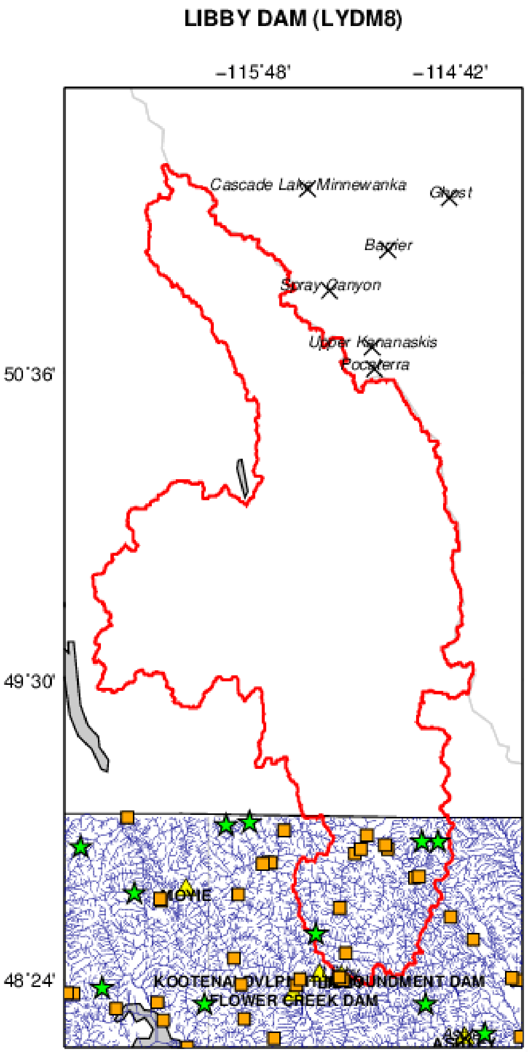
Best-performing forecasts | ESP forecasts | Skill Plots | Back to Top

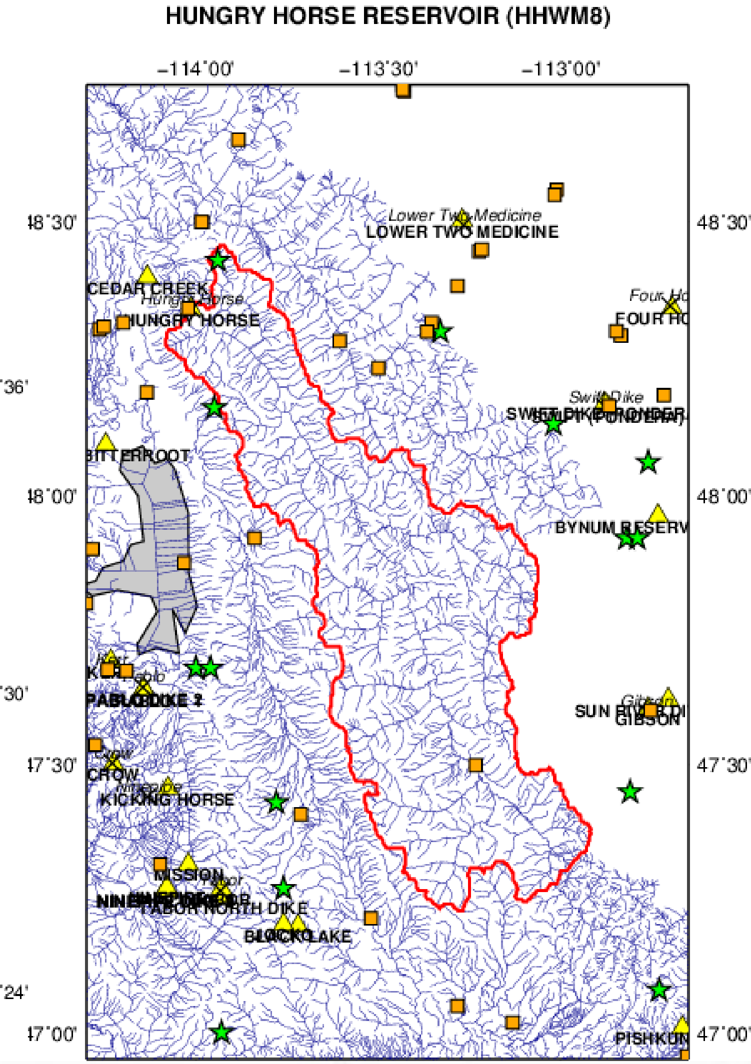


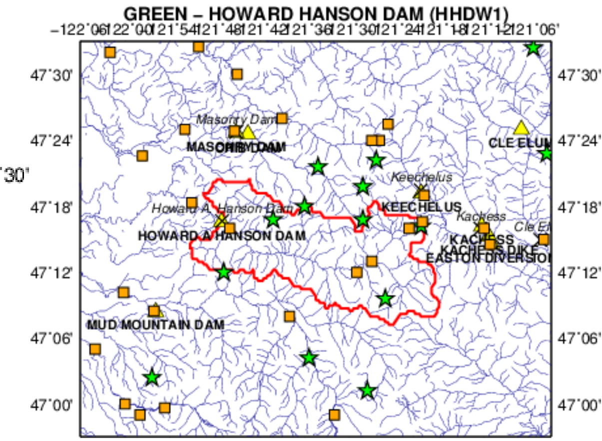
data (CSV)

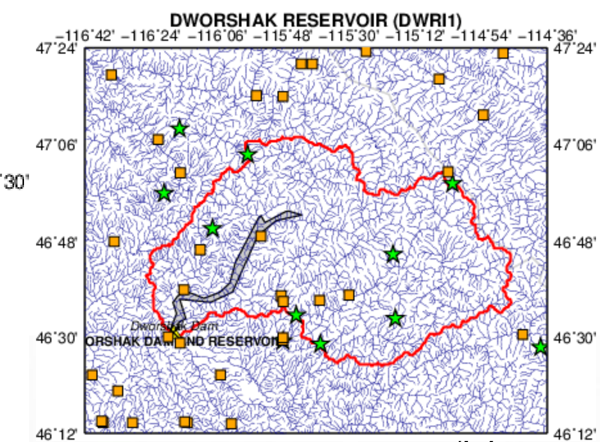
http://www.ral.ucar.edu/staff/wood/case_studies_wr/

WR case studies



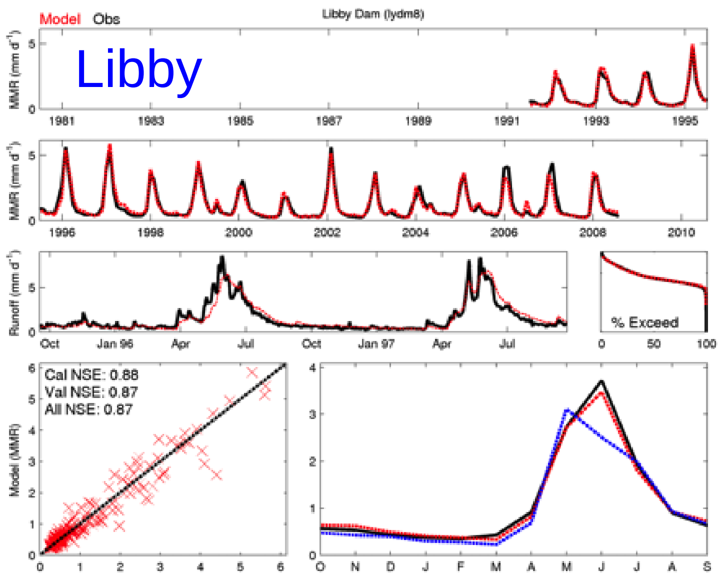


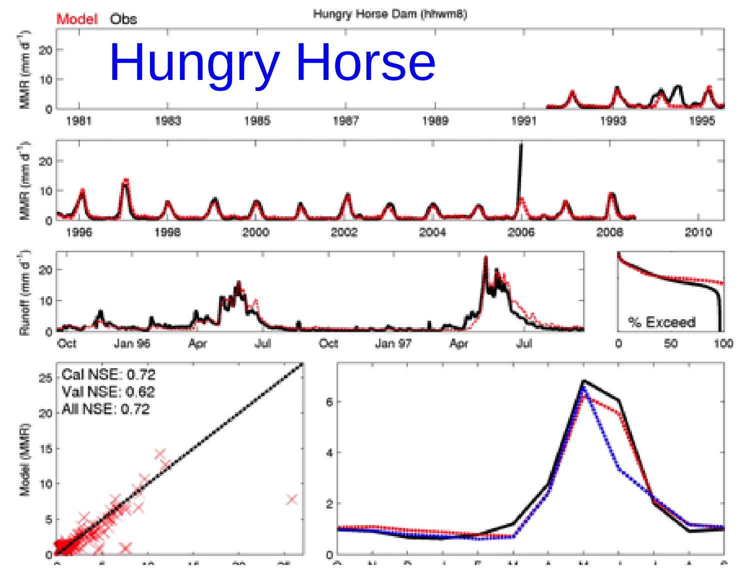




Hydrologic Ensemble Prediction EXperiment

WR case studies – model approach 1



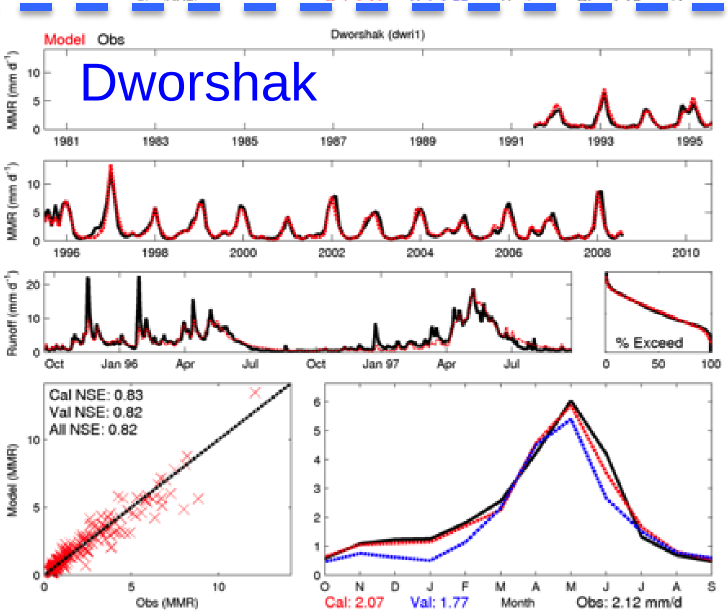


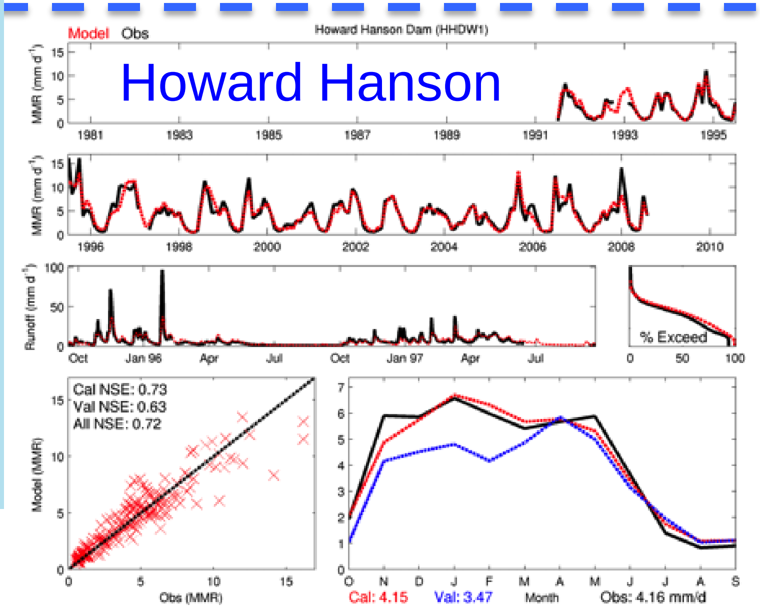
2-3 elevation zone Sac/Snow17/UH models using RFC zone delineations

Auto calibrated using SCE

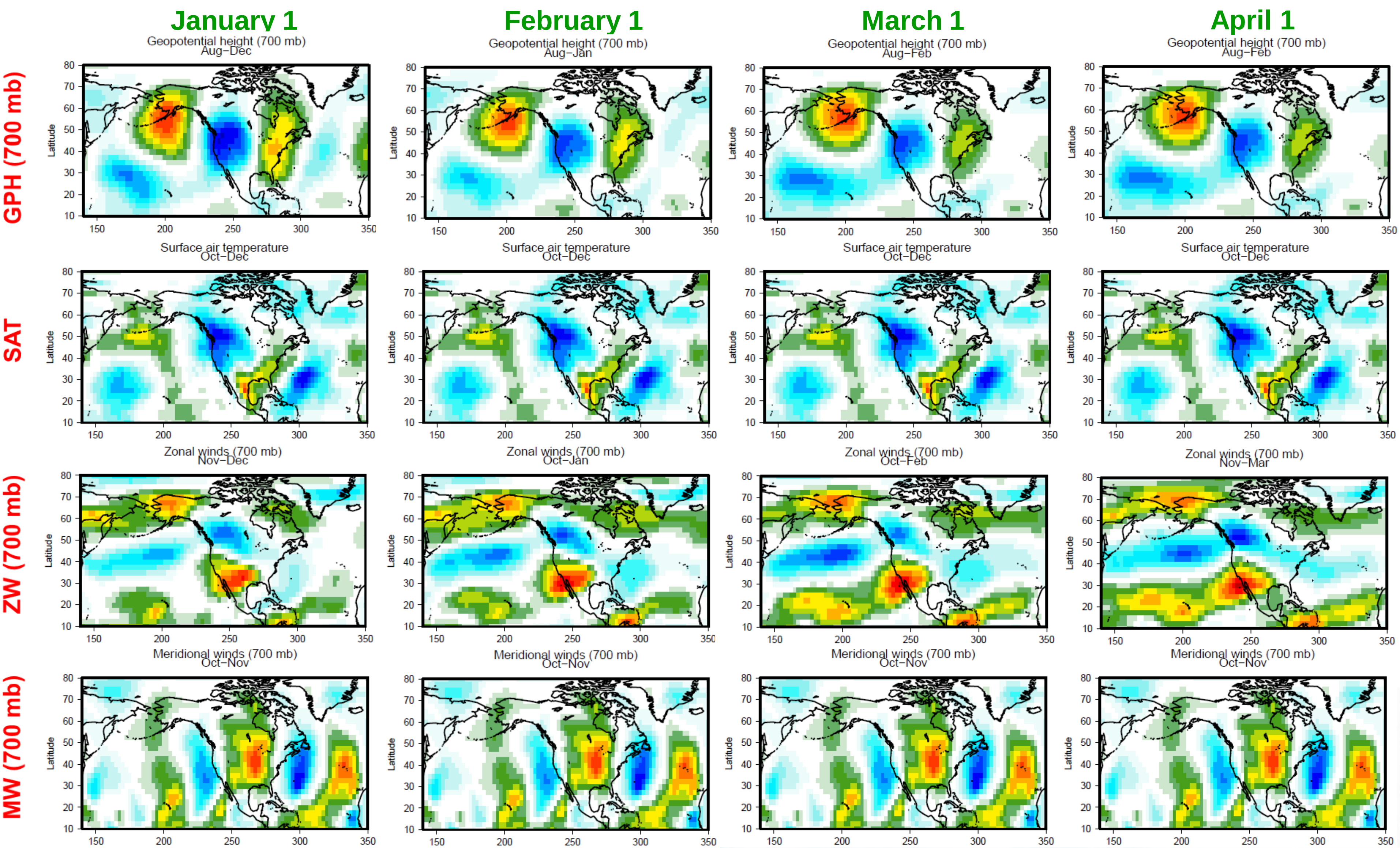
Forcings used:

- Daymet,
- NLDAS2
- Maurer
- Newman ensemble

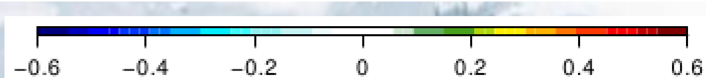




Climate information example: real-time analyses

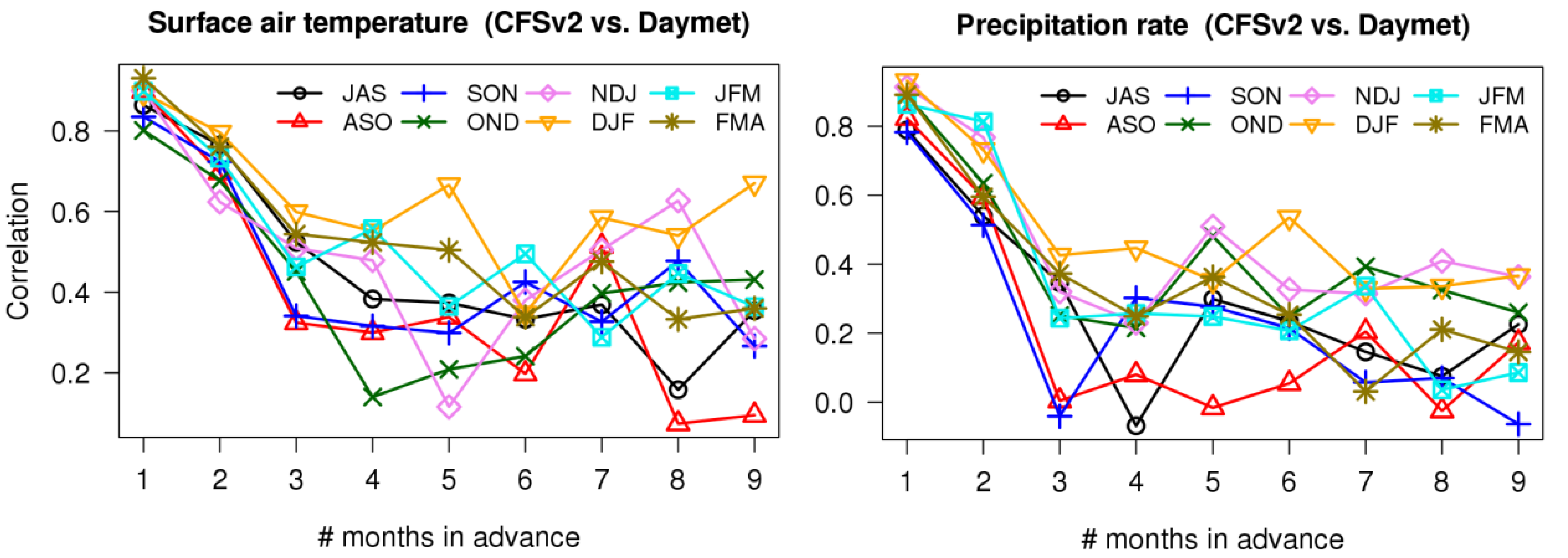


Crystal River Abv. Avalanche Crk.



Also leveraging climate forecast (CFSv2)

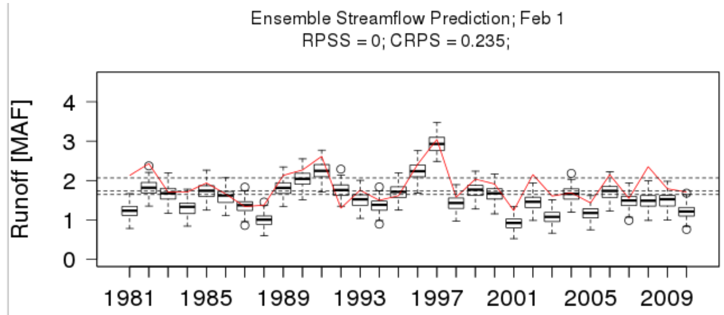
Correlations of CFSv2 precip & temperature with seasonal watershed climate

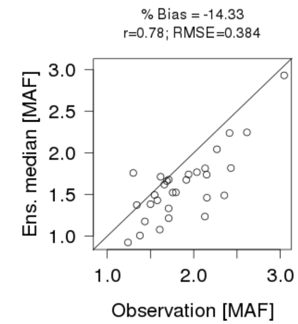


Example seasonal runoff volume hindcasts

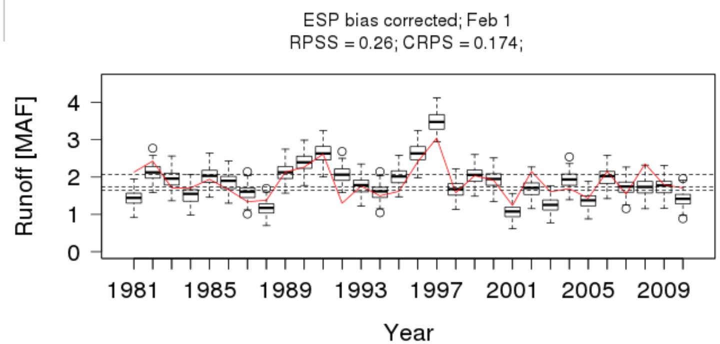
Hungry Horse Reservoir Inflow
Lead time: February 1 for April-July

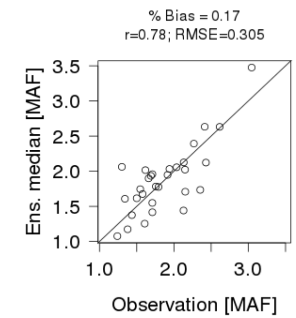
Raw ESP

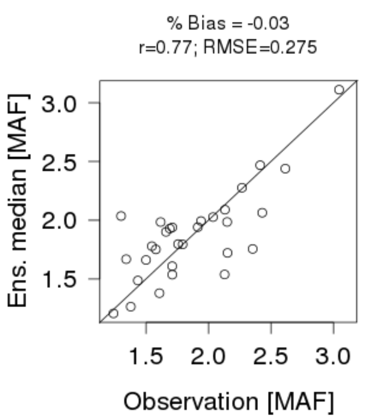




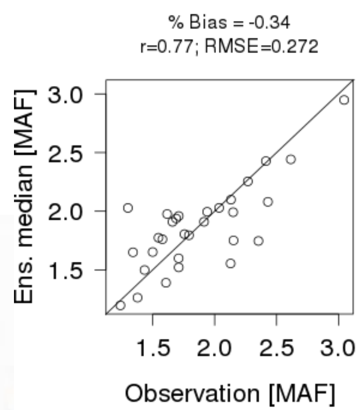
Bias corrected ESP



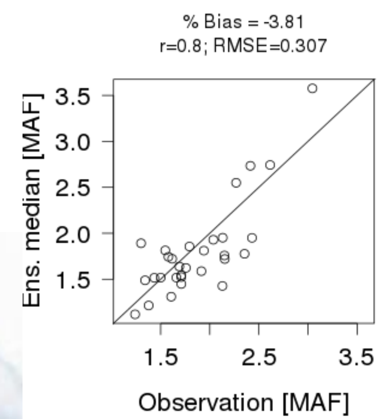




BC-ESP + Best. Stat. Clim. Equal Weights



BC-ESP + Best. Stat. RMSE weighting

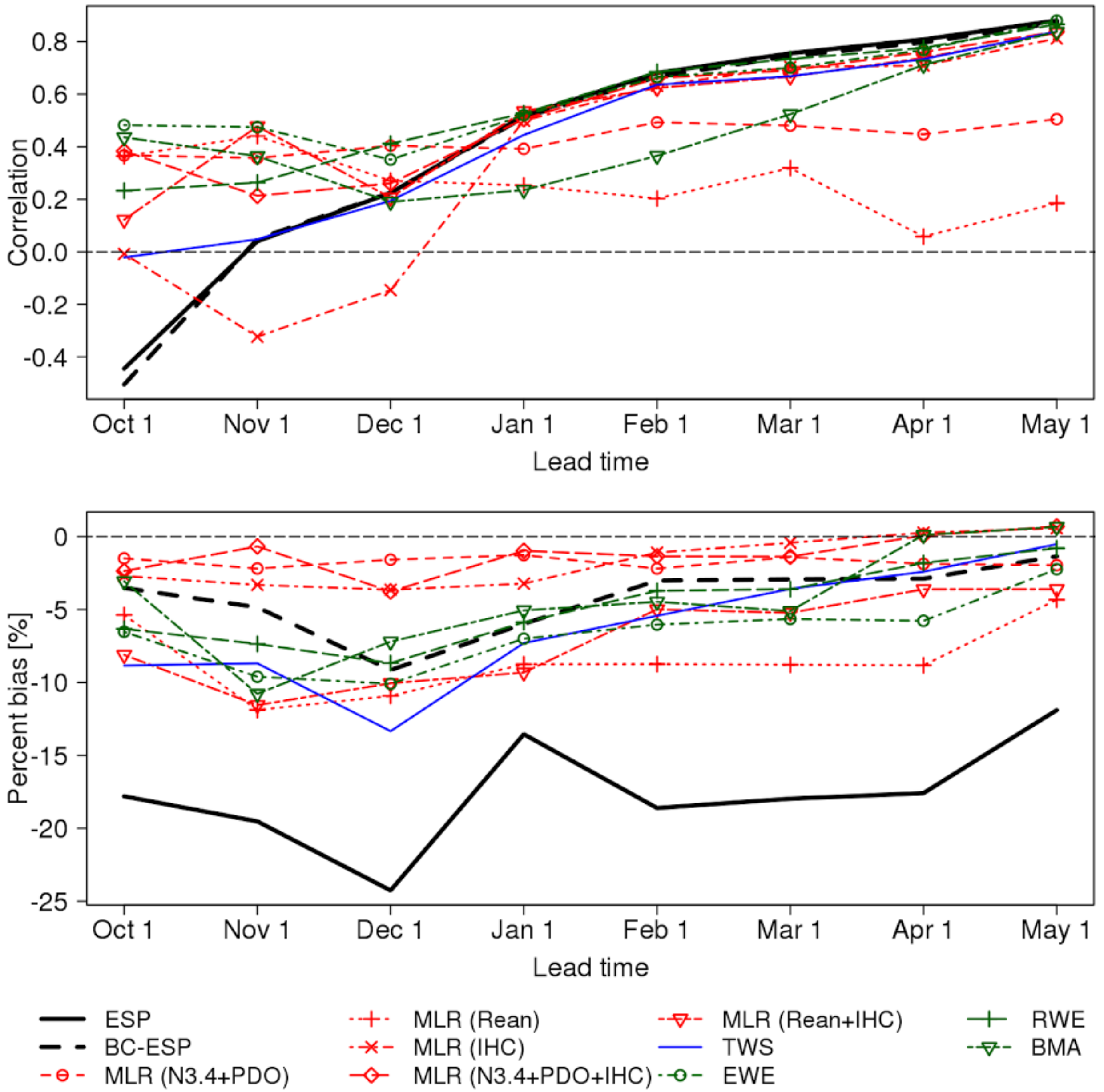


Trace weighting (Land) RMSE weighting

Hindcast-based skill evaluation

Hindcasts allow for skill evaluation of various approaches to water supply prediction using various metrics

- Correlation, Bias
- CRPS
- Reliability

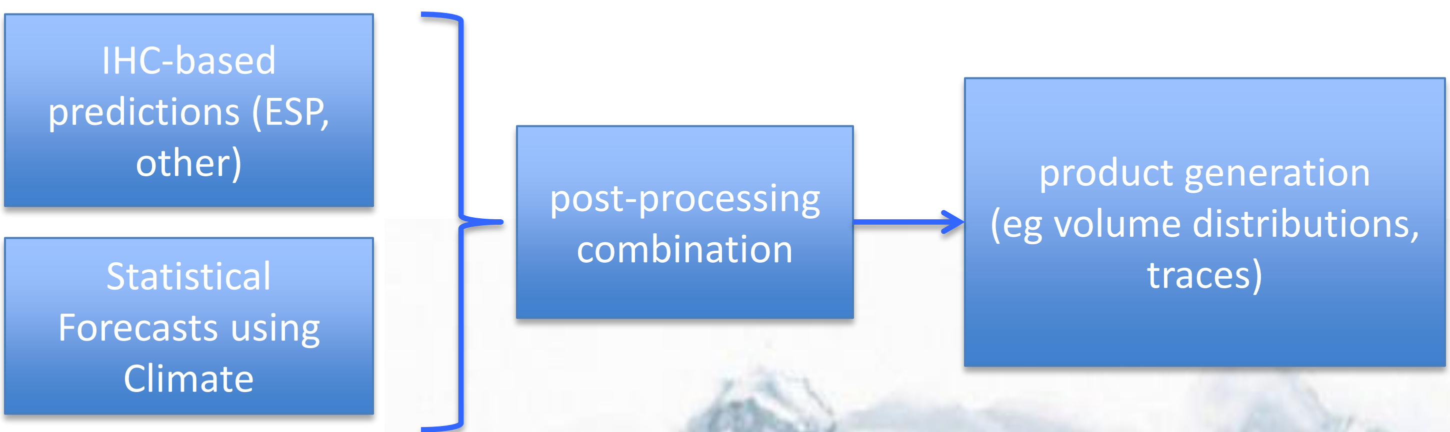


Hydrologic Ensemble Prediction E

Seasonal Forecast Findings/Strategy

- ESP with post-processing improves on ESP
- Climate predictors alone offer moderate forecast skill
- ESP in combination with climate information is more skillful than ESP alone (until late spring in snow-driven regions)

- A hierarchical framework that combines IHC-based predictions with climate or other predictors often works better than a trace-weighting scheme for ESP
  - note -- requires a hindcast-able ESP



Intercomparison Experiment Outline - example

1. Set leads/participants (solicit through HEPEX)
2. Coordinate:
   - define study basins
   - protocol for evaluation
   - scope/timeline of experiments
3. Assemble data, models, methods
4. Approach Intercomparisons
   - What is the marginal benefit of dynamical/complex approaches over statistical/simpler ones for various types of prediction? Where are dynamics necessary?
5. Dissemination / Outreach
   - What are useful ways of communicating results
   - Website, publication, also local interaction with users

Thoughts?