Development of a seasonal climate and streamflow forecasting testbed for the Colorado River Basin

Andy Wood

and Kevin Werner

NOAA / NWS

Colorado Basin River Forecast Center

Presentation

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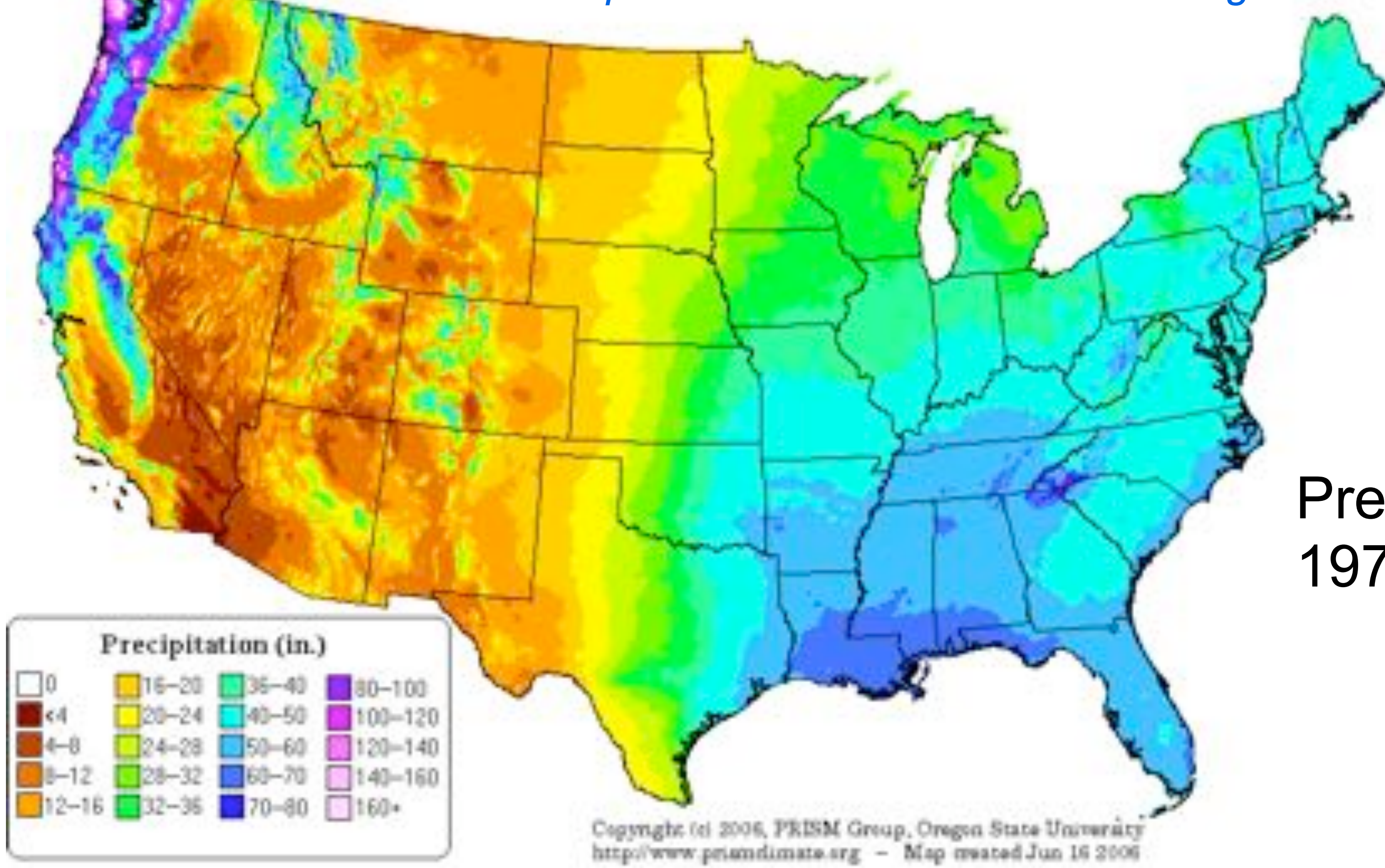
The Arid Lands

Many droughts will occur; many seasons in a long series will be fruitless; and it may be doubted whether, on the whole, agriculture will prove remunerative.

John Wesley Powell, 1879

Report on the Lands of the Arid Region of the United States



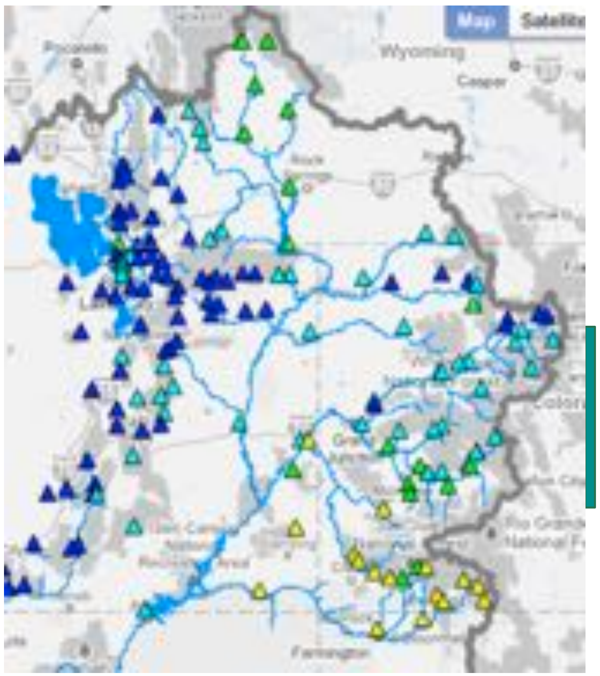
Precipitation, 1971-2000

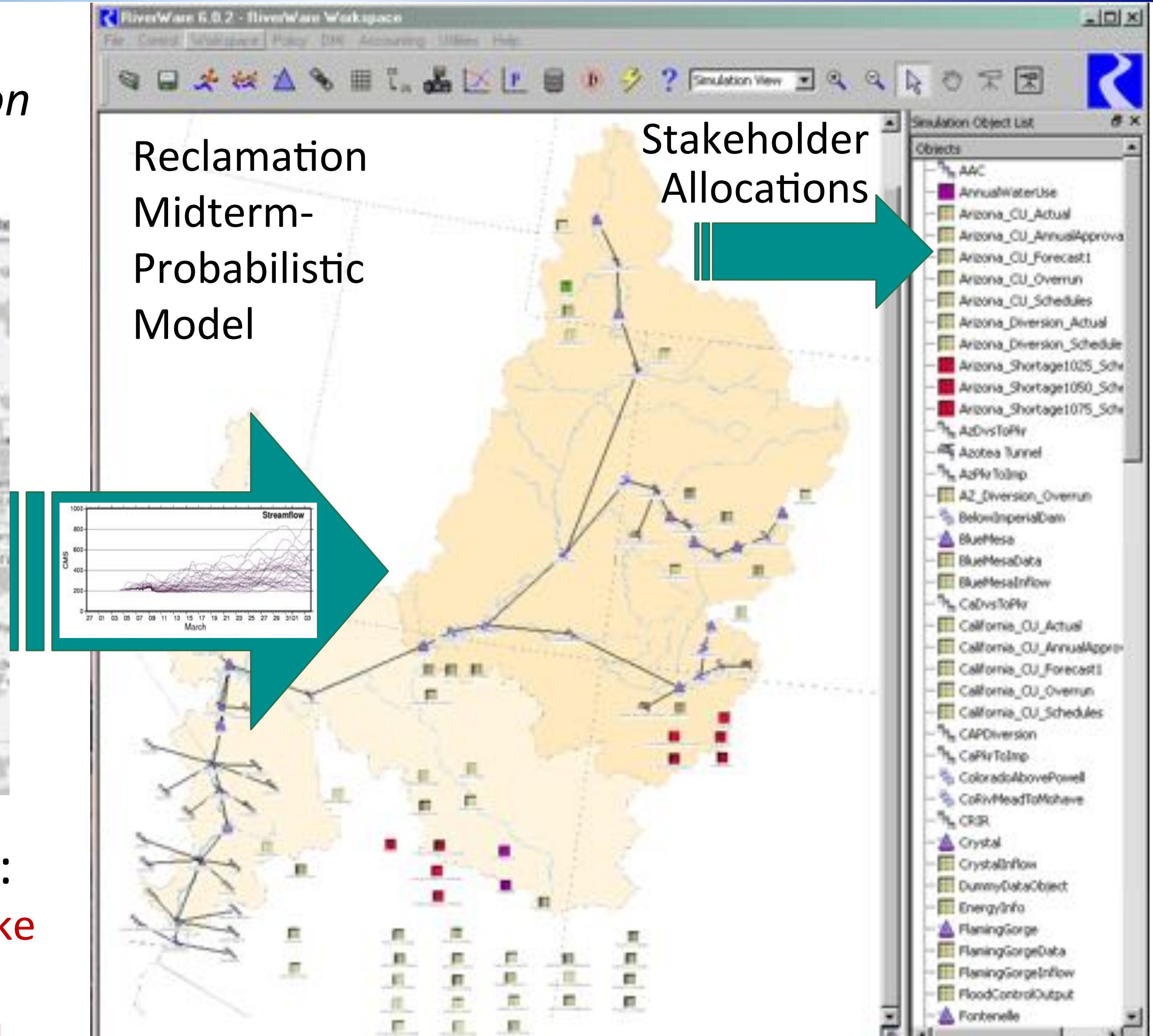
Colorado River

- 25 million people rely on Colorado River water
- 3.5 million acres of irrigation
- Water worth >$4B per year ($330/AF base cost)
- 85% of runoff comes from above 9000 feet
- Mean annual discharge is about … (?)
- Storage capacity (reservoirs) ~60 MAF, or 4-5 times mean annual flow

Forecasts and Water Management

CBRFC ensemble flow forecasts for Reclamation water management



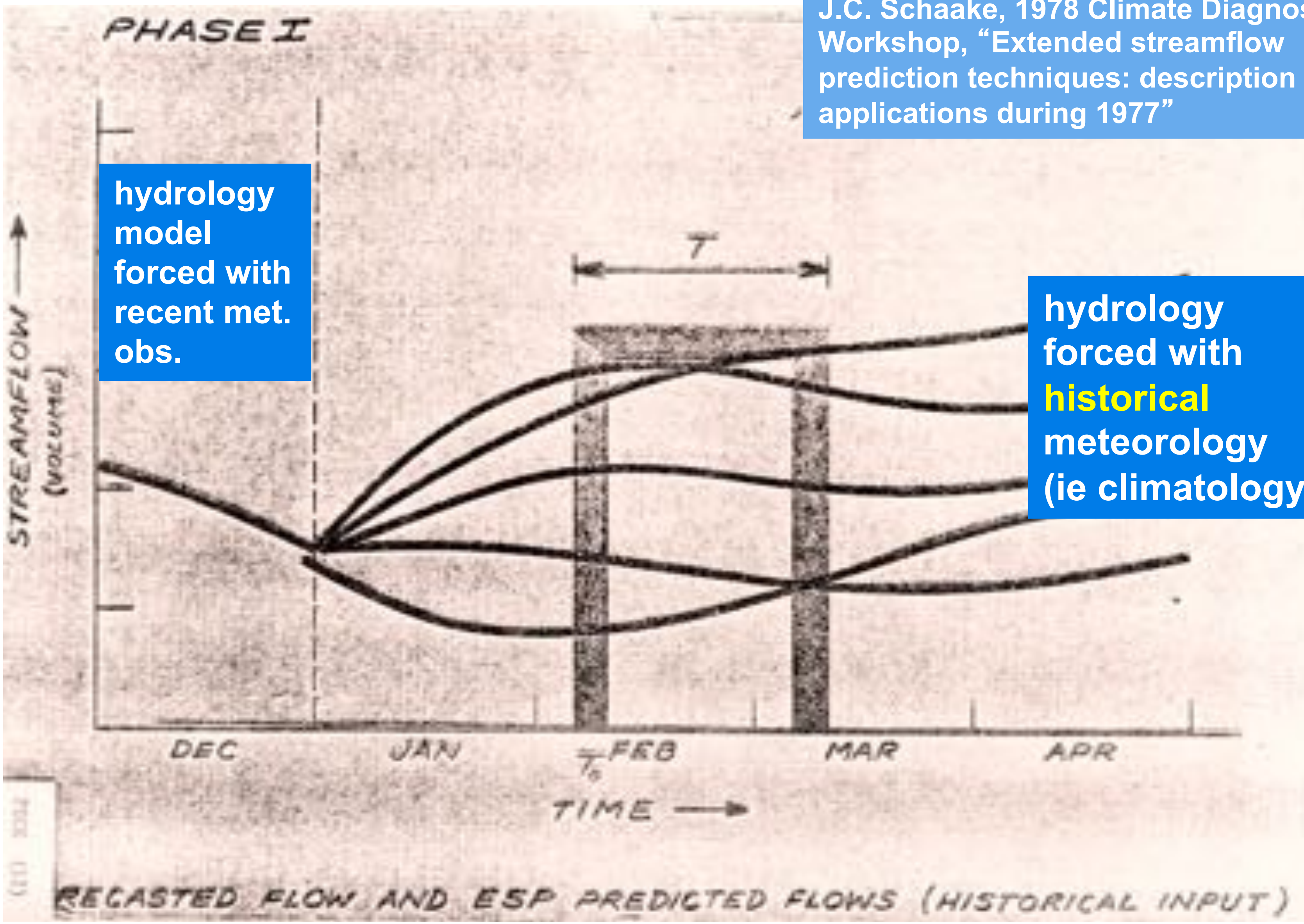


Forecast impacts, e.g.:
if WY12 is wet enough, Lake Mead hits surplus levels, MWD gets water ~ $150M

Graphic from Dr. Katrina Grantz, Bureau of Reclamation

NWS ensemble forecast approach (ESP), 1970s - present

J.C. Schaake, 1978 Climate Diagnostics Workshop, “Extended streamflow prediction techniques: description and applications during 1977”



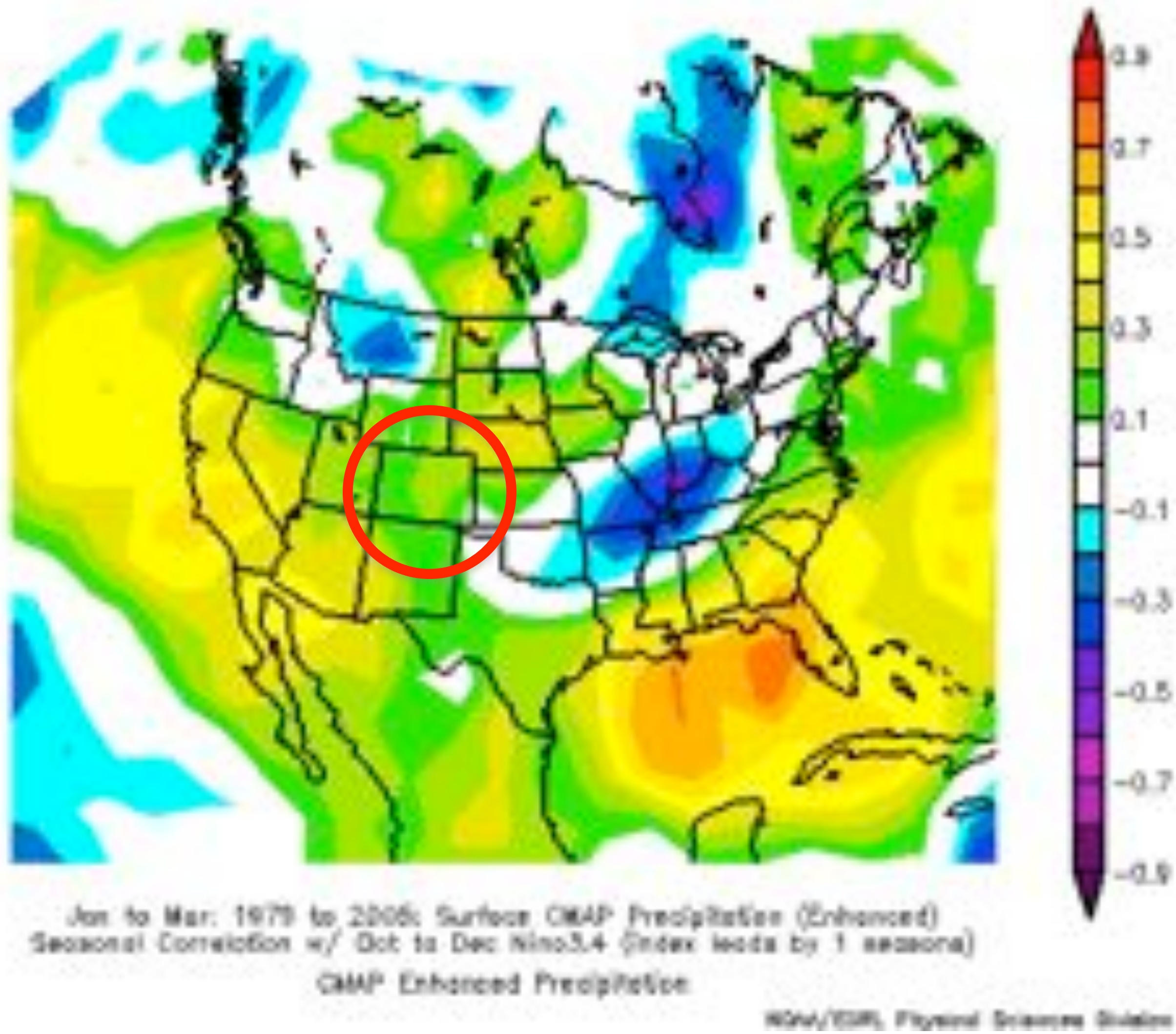
hydrology model forced with recent met. obs.

hydrology forced with historical meteorology (ie climatology)

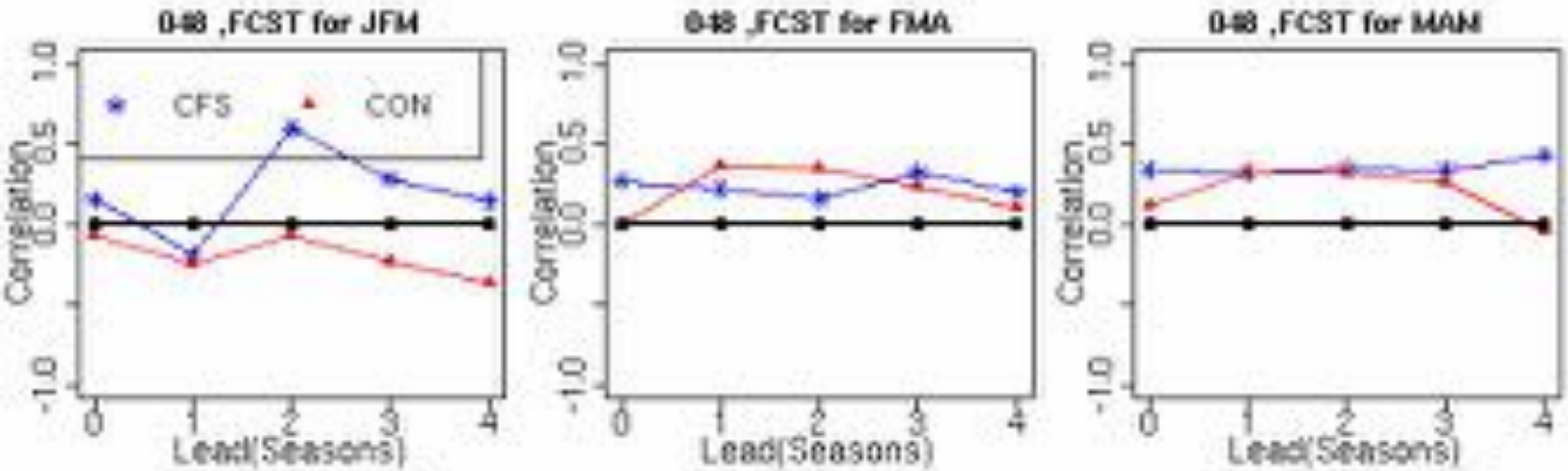
Upper Colorado forecast skill challenges

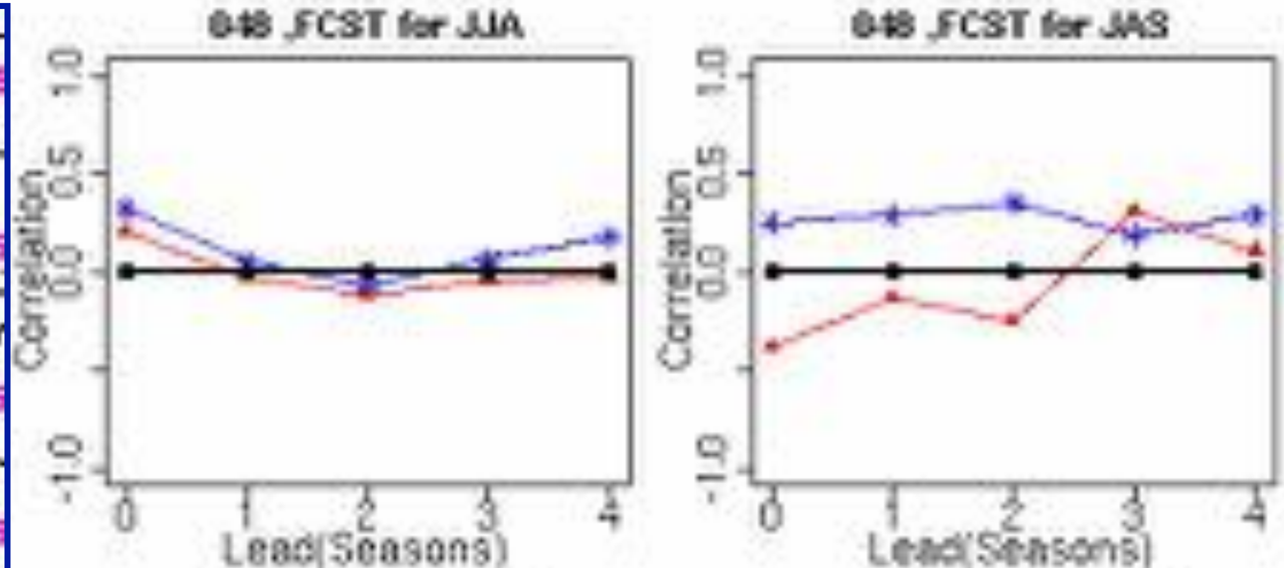
- ISI climate predictability is relatively ***limited*** in our region (CB)
- water management in 7 states depends on regional climate and flow forecasts

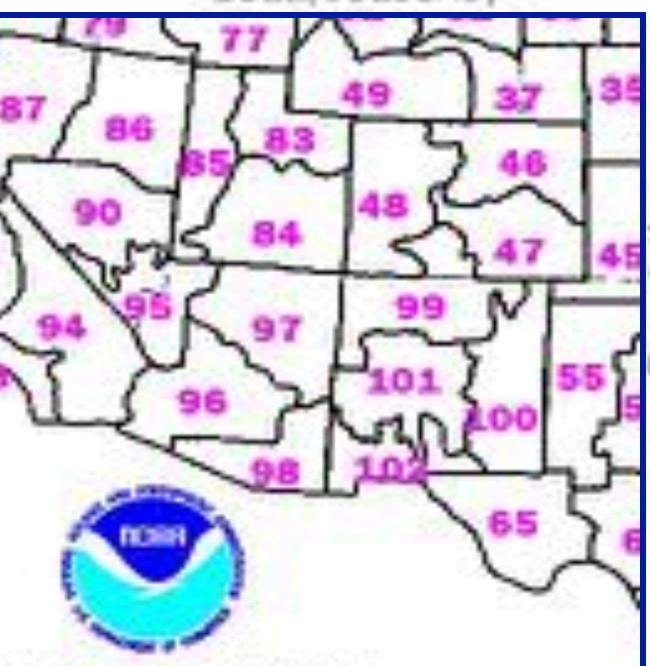
plot -- JFM Precip correlation with Nino 3.4, lag 1 season



Correlation, CD 48

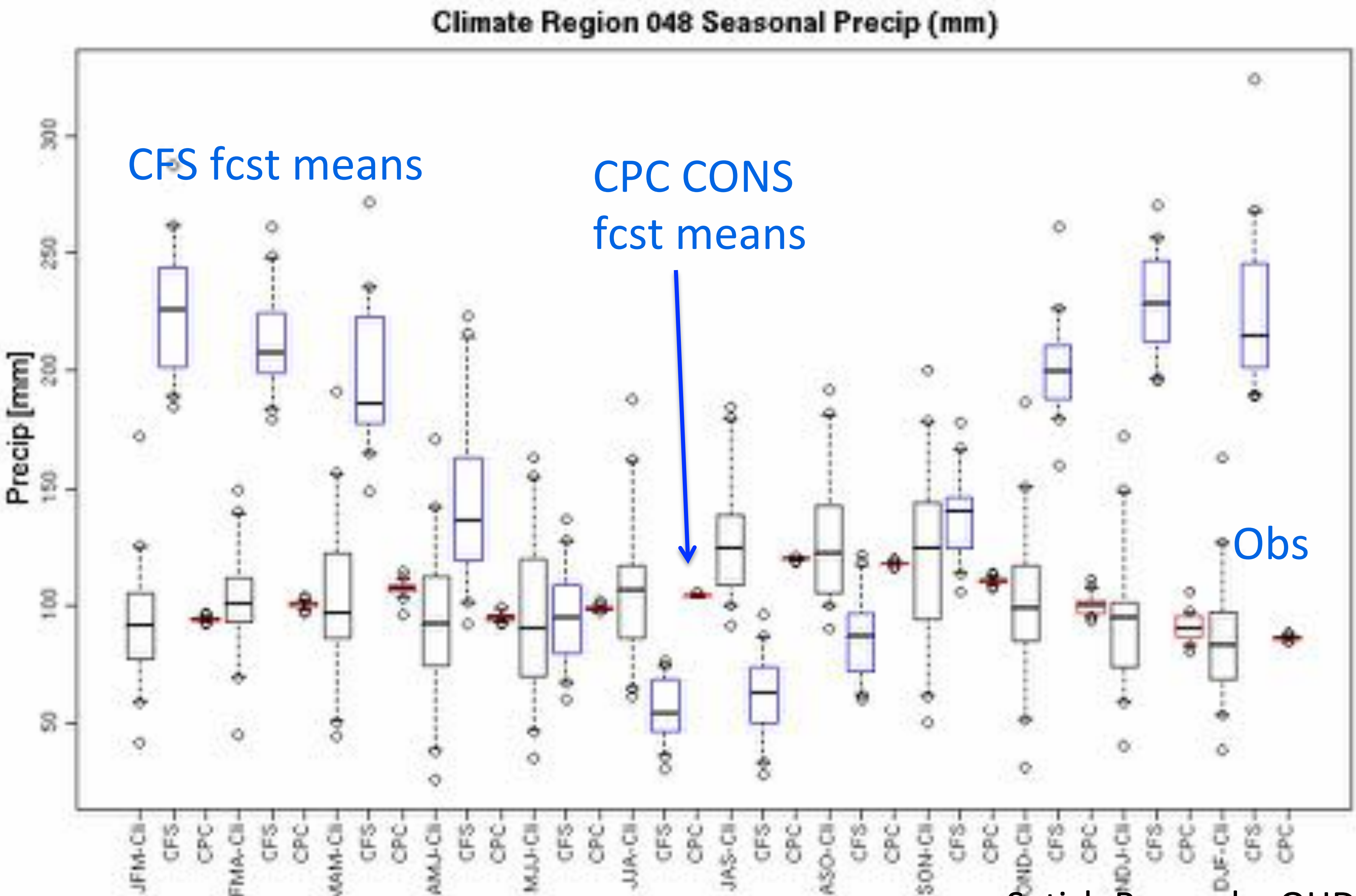






Satish Regonda, OHD

Seasonal Precipitation Climatologies



Satish Regonda, OHD

Upper Colorado forecast example

- ❑This forecast verified well for CONUS
- ❑The precip in particular verified poorly for the upper Colorado R. basin
- ❑Flow forecasts based on this CFS prediction were worse than using climatology

(from Simon Wang, USU)

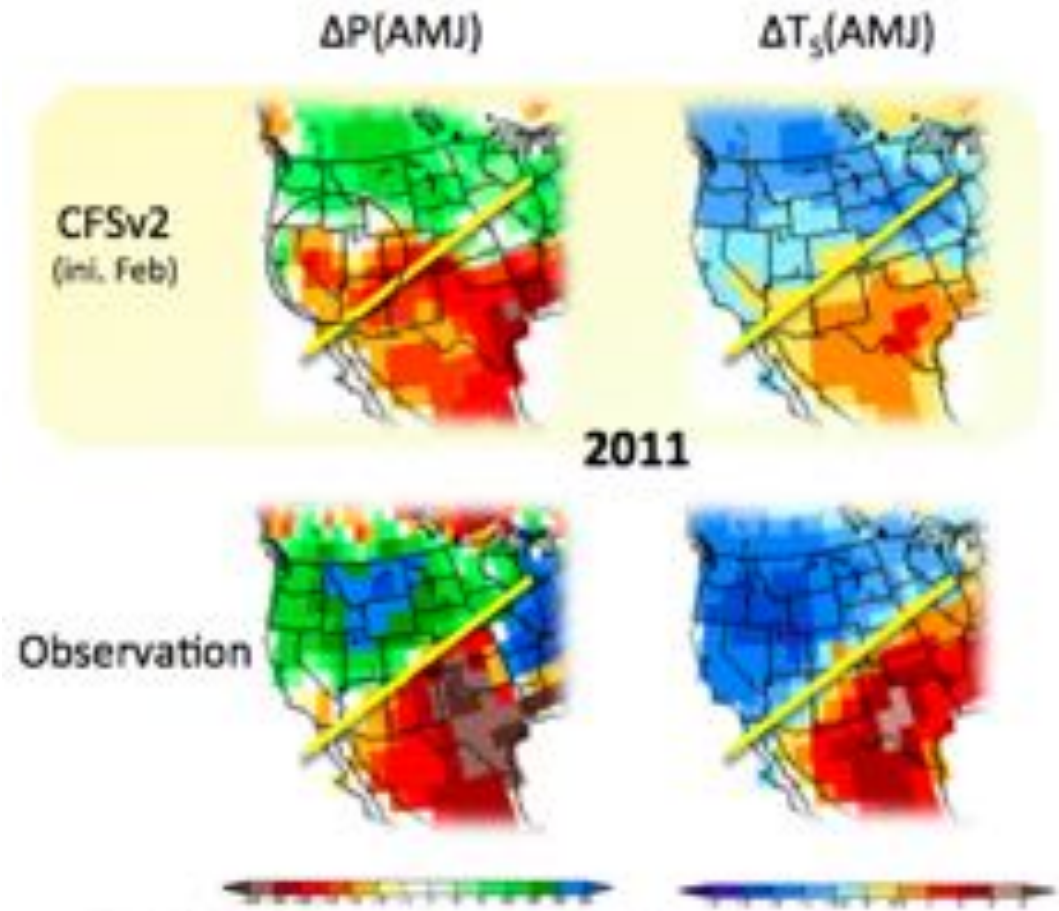


Fig. 1 CFSv2 seasonal precipitation (P) and temperature (T_S) anomaly forecasts from February 2011 and verifying observations. The intermountain West (with low skill) is outlined by black cicle in the upper left panel.

Climate science has advanced…

in research world, not operations

- 15 years of applied climate and flow forecasting research pertaining to western US

Barnston, A.G., et al: 1994, ***Long-lead seasonal forecasts---where do we stand?***, BAMS	Trenberth, K. E. 1997. ***The definition of El Niño.*** BAMS
Wood, A. W., A. Kumar, and D. P. Lettenmaier (2005), ***A retrospective assessment of National Centers for Environmental Prediction climate model-based ensemble hydrologic forecasting in the western United States***, J. Geophys. Res.	Piechota, T.C., J.A. Dracup, and R.G. Fovell, 1997. ***Western U.S. Streamflow and Atmospheric Circulation Patterns During El Niño-Southern Oscillation (ENSO).*** Journal of Hydrology
Bracken, C., B. Rajagopalan, and J. Prairie (2010), ***A multisite seasonal ensemble streamflow forecasting technique.*** Water Resour. Res.	Piechota, T.C., Dracup, J.A.,1996, ***Drought and Regional Hydrologic Variations in the United States: Associations with the El Niño/Southern Oscillation.*** Water Resources Research
Ropelewski, C.F.; and M.S. Halpert. 1986. **North American precipitation and temperature patterns associated with the El Niño–Southern Oscillation (ENSO).** MWR	Garen, D.C., 1992, ***Improved Techniques in Regression-Based Streamflow Volume Forecasting.*** JWRPM
Bracken, C; Rajagopalan, B; Prairie, J (2010). ***A multisite seasonal ensemble streamflow forecasting technique.*** Water Resour. Res.	Hamlet, A. F., Lettenmaier, D. P., 1999: ***Columbia River Streamflow Forecasting Based on ENSO and PDO Climate Signals.*** JWRPM
Grantz, K., B. Rajagopalan, M. Clark, and E. Zagona, 2005: ***A technique for incorporating large-scale climate information in basin-scale ensemble streamflow forecasts.*** Water Resour.Res.	Piechota, T. C. and Dracup, J. A., "***Long-range streamflow forecasting using ENSO information: Application to the Columbia River Basin***" (1997). *Faculty Publications (CEE)*
Grantz, K; Rajagopalan, B; Zagona, E; Clark, M (2007), ***Water management applications of climate-based hydrologic forecasts: Case study of the Truckee-Carson River Basin.*** JWRPM	Wang, S.-Y., R. R. Gillies, J. Jin, and L. E. Hipps (2009), ***Recent rainfall cycle in the Intermountain Region as a quadrature amplitude modulation from the Pacific decadal oscillation***, Geophys. Res. Lett.
Najafi, M., Moradkhani H., and Wherry, S., "***Statistical Downscaling of Precipitation using Machine Learning with Optimal Predictor Selection***", JHE	Moradkhani, H., Meier, M., "***Long-Lead Water Supply Forecast using Large-scale Climate Predictors and Independent Component Analysis***", JHE
Switanek, Matthew B., Peter A. Troch, Christopher L. Castro, 2009: ***Improving Seasonal Predictions of Climate Variability and Water Availability at the Catchment Scale.*** JHM	Sankarasubramanian, A., U. Lall, N.Devineni and S. Espuneva, ***Utility of Operational Streamflow Forecasts in Improving within-season Reservoir Operation***, IACM

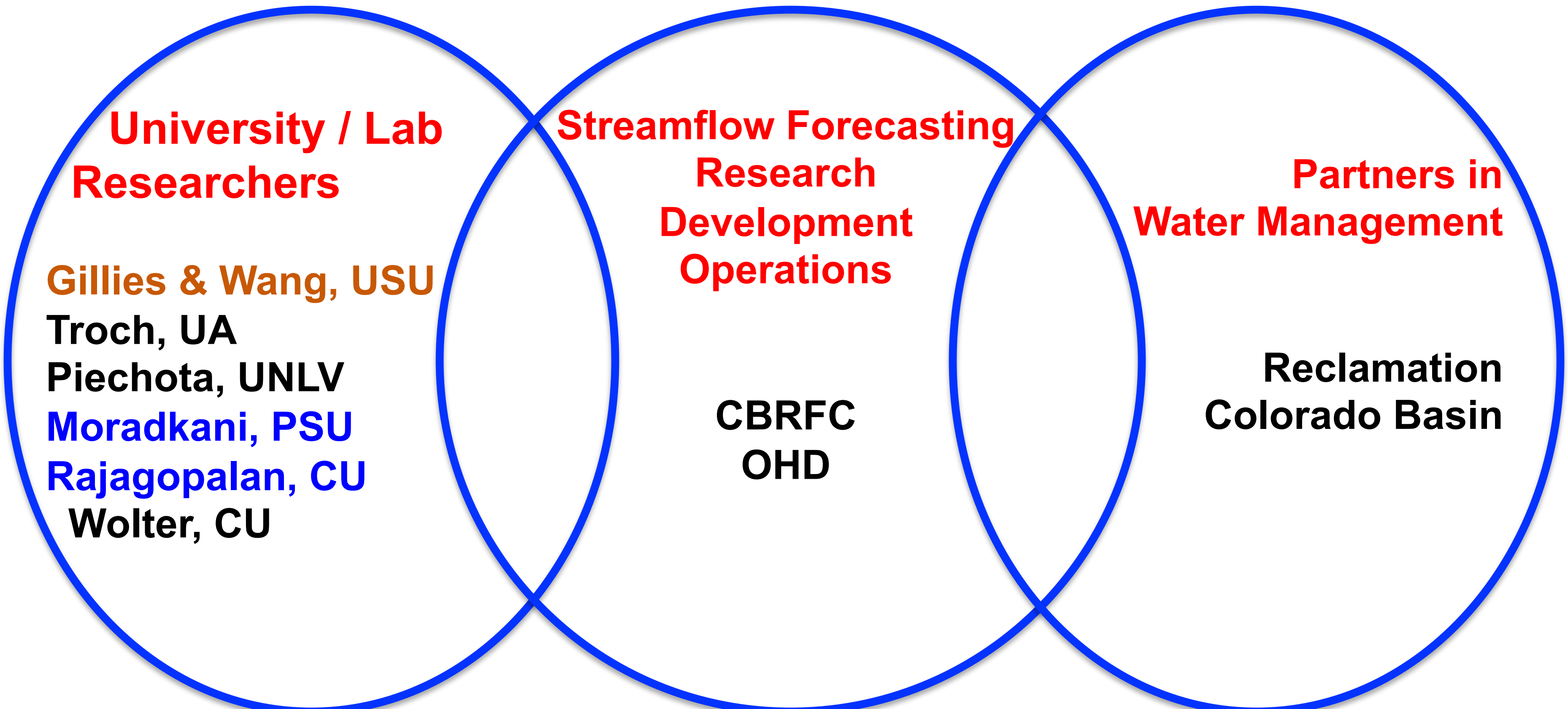
- Variable use of findings within operational water prediction and management
- One of the biggest usage gaps: the upper Colorado River Basin
- Motivation: Increasing scrutiny of Colorado River water management

SI/Y2 Climate and Streamflow Forecasting Workshop

NOAA/NWS Colorado Basin River Forecast Center
Salt Lake City, UT – March 21-22, 2011

Organized by
CBRFC
Reclamation

Sponsored by
Colorado Water Conservation Board
NIDIS



Others: Becky Smith (student, CSU); Sponsors (CWCB) and Consultant (RTI)

Outcomes: (1) future workshop; ***(2) forecasting testbed***

Testbed Concept

Motivation

Evaluate climate forecast approaches in context of water management

Objectives

- reflect the forecasting challenge that's important to RFC and stakeholders, e.g.,
    - initialization times (Aug 1 … July 1)
    - predictands in time: sub-seasonal, seasonal, year 2
    - predictands in space: catchments driving management

- be consistent with pathways available for innovation
    - educate research community about operational constraints

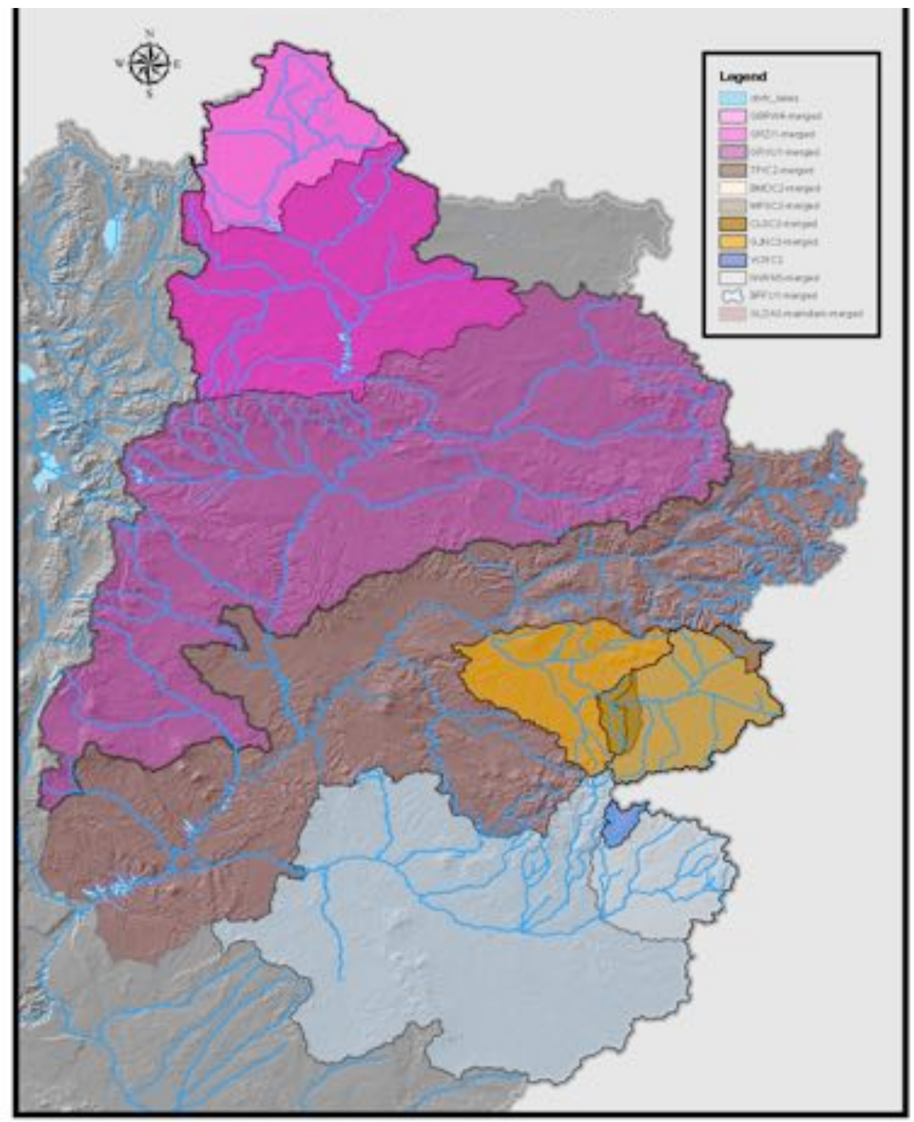
- **establish baselines for state of practice**

- make similar approaches relevant to Colorado Basin and inter-comparable
    - common metrics as well as predictands

- results basis for conversation with RFC forecasters about changing approach

A river-oriented climate and flow forecast testbed

Testbed basins



Testbed Data

Testbed Datasets

The watershed data in the table below are aggregated from a number of CBRFC forecast segments to encompass major drainage areas in the 8 major river basins that directly support BOR probabilistic forecasting.

Watershed Name	Obs MAP/MAT Timeseries (in,F)	Obs Flow Timeseries	Clim MAP/MAT Hindcasts	Clim-ESP Flow Hindcasts	CFS MAP/MAT Hindcasts	CPC-cons MAP/MAT Hindcasts
Gunnison R abv Blue Mesa (BMDC2)	monthly	tgz	tgz	tgz	tgz	tgz
San Juan River nr Navajo Res Archuleta (NVRN5)	monthly	tgz	tgz	tgz	tgz	tgz
Green R at Flaming Gorge Res Flaming Gorge Dam (GRNU1)	monthly	tgz	tgz	tgz	tgz	tgz
Gunnison R at Morrow Point Res (MPSC2)	monthly	tgz	tgz	tgz	tgz	tgz
Taylor R at Taylor Park Res (TPIC2)	monthly	tgz	tgz	tgz	tgz	tgz
Green R Nr Fontanelle Res Fontanelle (GBRW4)	monthly	tgz	tgz	tgz	tgz	tgz
Gunnison R at Crystal Res (CLSC2)	monthly	tgz	tgz	tgz	tgz	tgz
Los Pinos Nr Vallecito Res Bayfield (VCRC2)	monthly	tgz	tgz	tgz	tgz	tgz

The points in the table below are aggregated further to the outlets of 3 major tributaries above Lake Powell, and to Lake Powell itself.

Watershed Name	Obs MAP/MAT Timeseries (in,F)	Obs Flow Timeseries	Clim MAP/MAT Hindcasts	Clim-ESP Flow Hindcasts	CFS MAP/MAT Hindcasts	CPC-cons MAP/MAT Hindcasts
San Juan R nr Bluff (BFFU1)	monthly	tgz	tgz	tgz	tgz	tgz
Green R nr Green R (GRVU1)	monthly	tgz	tgz	tgz	tgz	tgz
Gunnison R nr Grand Junction (GJNC2)	monthly	tgz	tgz	tgz	tgz	tgz
Colorado R at Lake Powell Glen Cyn Dam (GLDA3)	monthly	tgz	tgz	tgz	tgz	tgz

Two Main Testbed Approaches to Prediction

Dynamical prediction with Statistical Downscaling

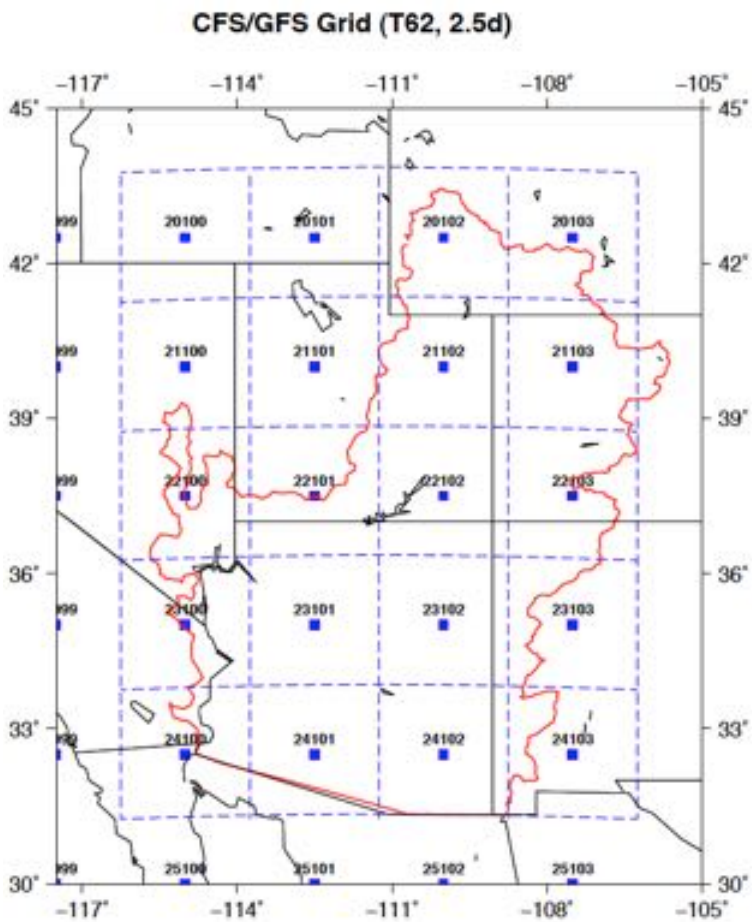
•CFSv2 ensembles, NMME ensembles with regressive / semi-parametric downscaling to watershed units (Schaake methods)
•NWS/OHD's main push as part of HEFS
•Has focused primarily on model output precipitation and temperature

Statistically relate climate system state to future climate and/or flow

•Predictors from ocean, land (eg Snotel, PDSI) and upper atmosphere
•Predictands chosen with best intentions, i.e., hydrologically relevant:

- spring runoff, temp
- winter precip

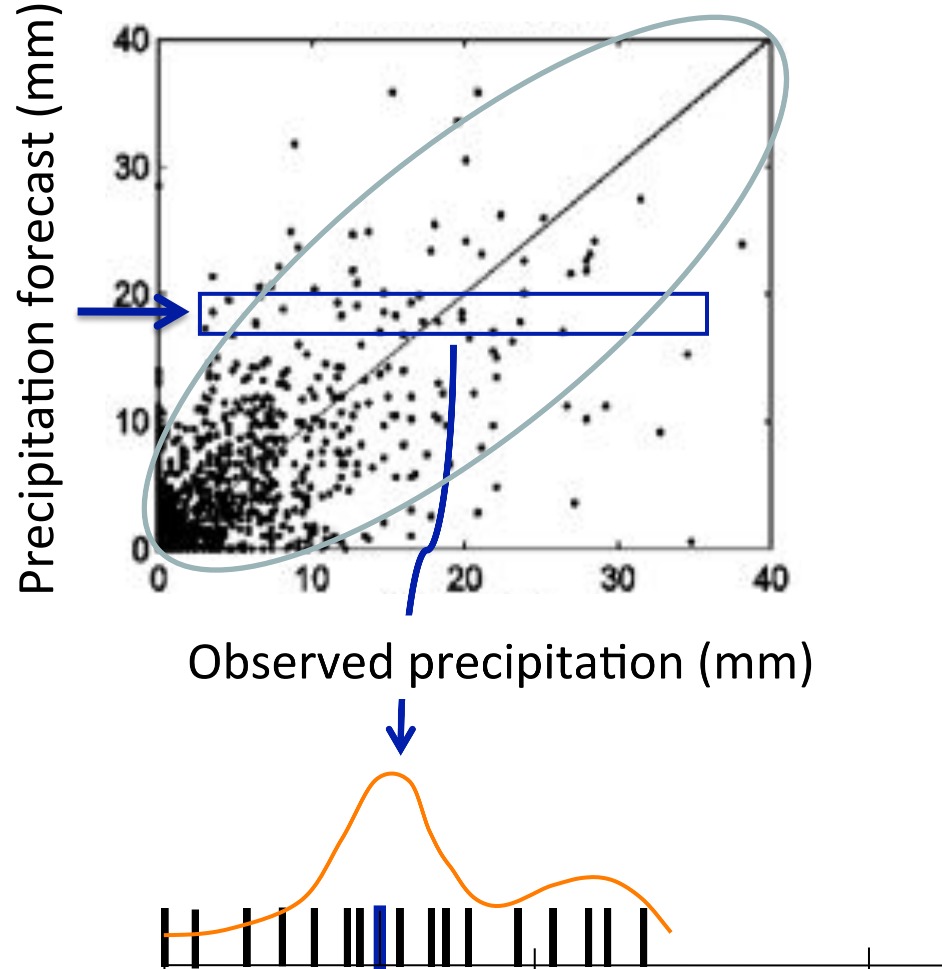
GFS/CFS Downscaling for Ens. Prediction



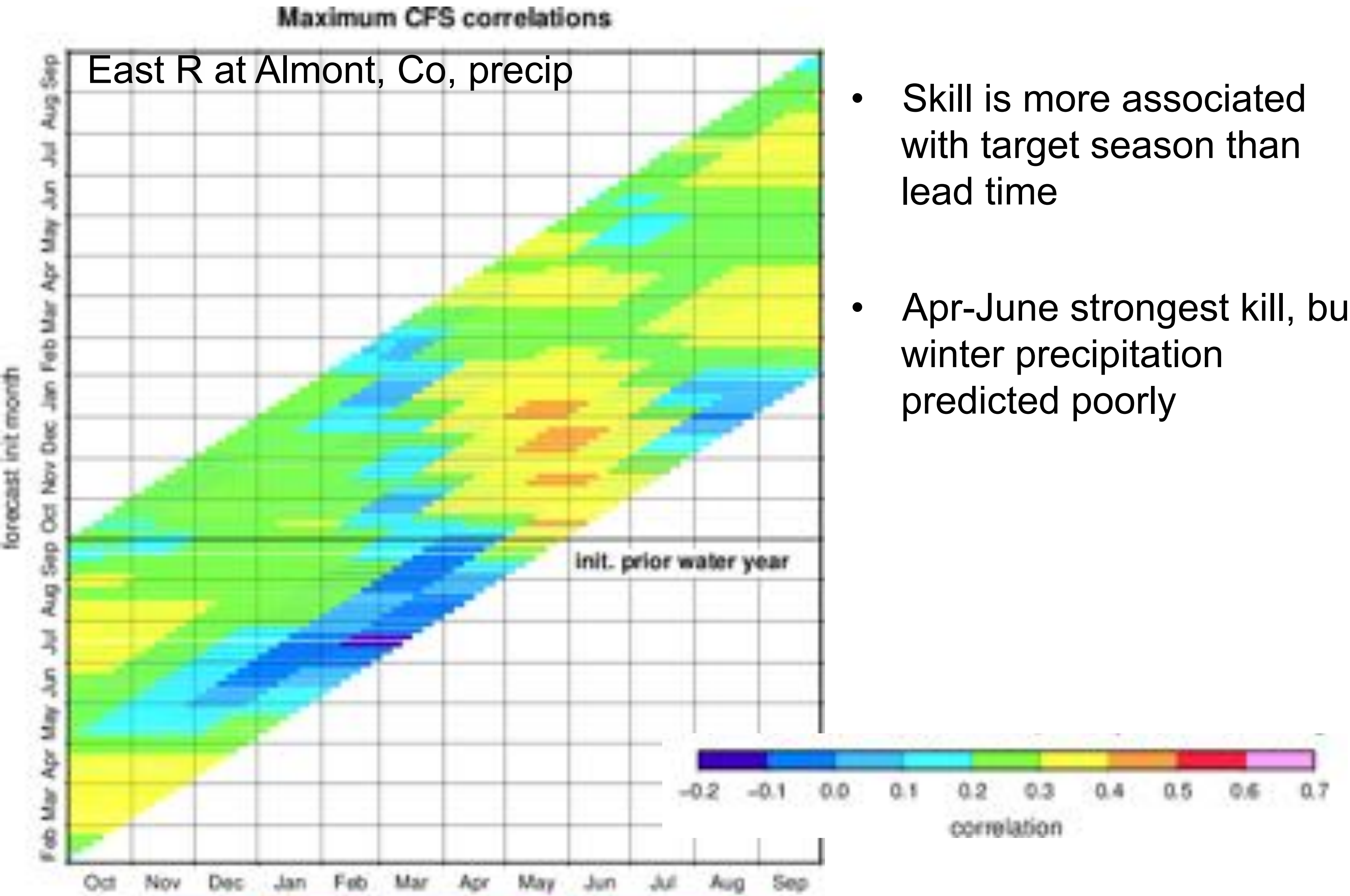
- Use only ensemble means
- Reconstruct ensemble spread based on past skill of means
- Described in Seo et al., 2006, HESS

Calibration / Downscaling

Archive of observed-forecast pairs



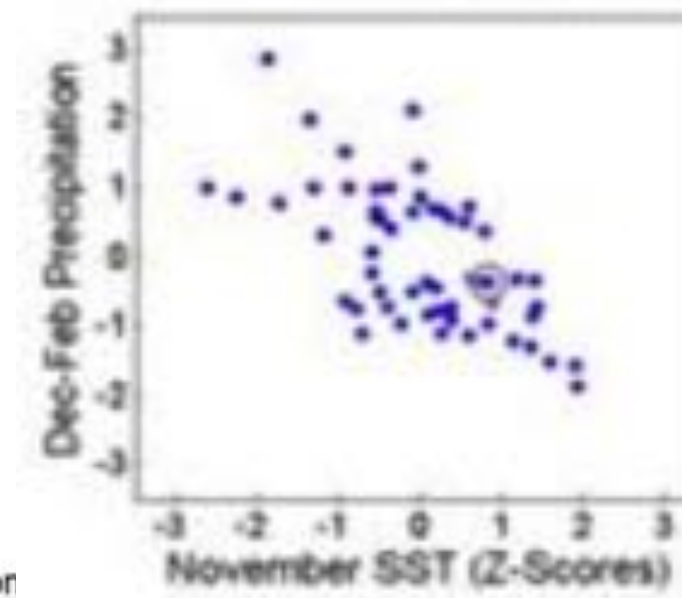
CFS skill evaluations in upper Colorado



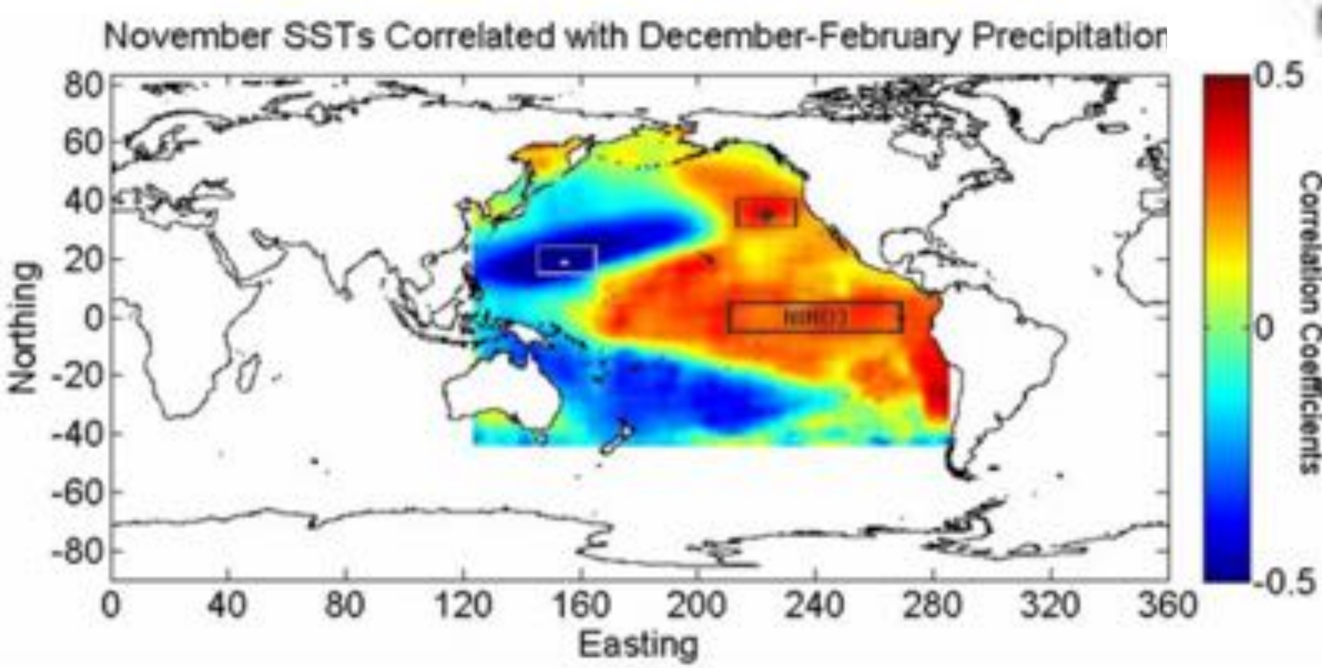
- Skill is more associated with target season than lead time
- Apr-June strongest kill, but winter precipitation predicted poorly

developing alternative statistical climate prediction approaches

For ENSO-challenged regions, standard indices (eg Nino 3.4) are not optimal



BSCP IMPROVING ON NINO3



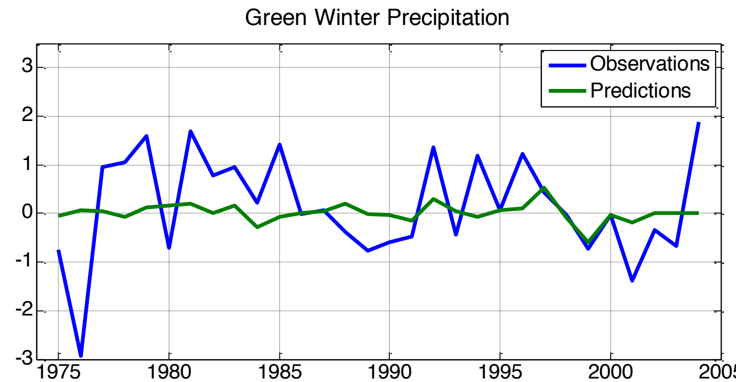
M. Switanek, P. Troch, U. of Arizona

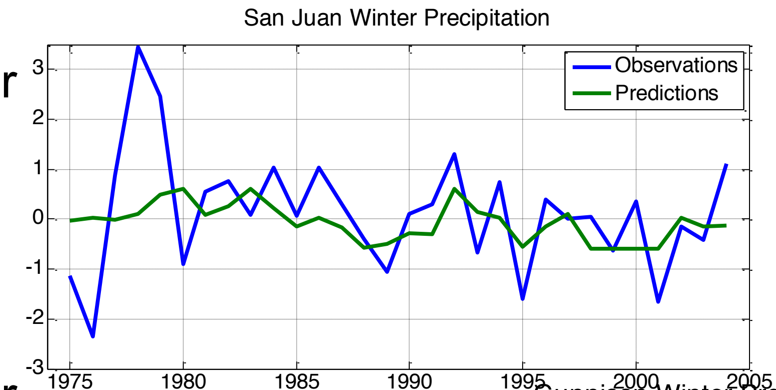
U of Arizona effort:
Matt Switanek, Peter Troch

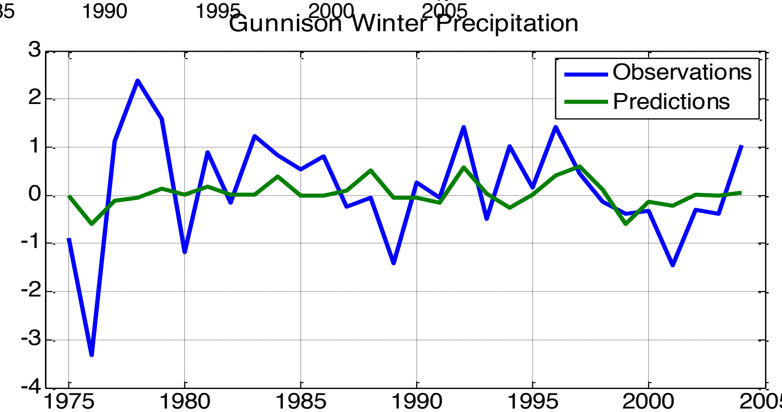
- **Goal**: Long lead precipitation / temperature forecasts for the Colorado Basin with improved skill over CPC forecasts

- **Method**: Statistical approach based on March – August global SST anomalies predicting Oct-Mar Precipitation and Temperature anomalies over major Colorado river sub-basins

- **Results**: Found improvement over CPC forecasts at the climate division scale

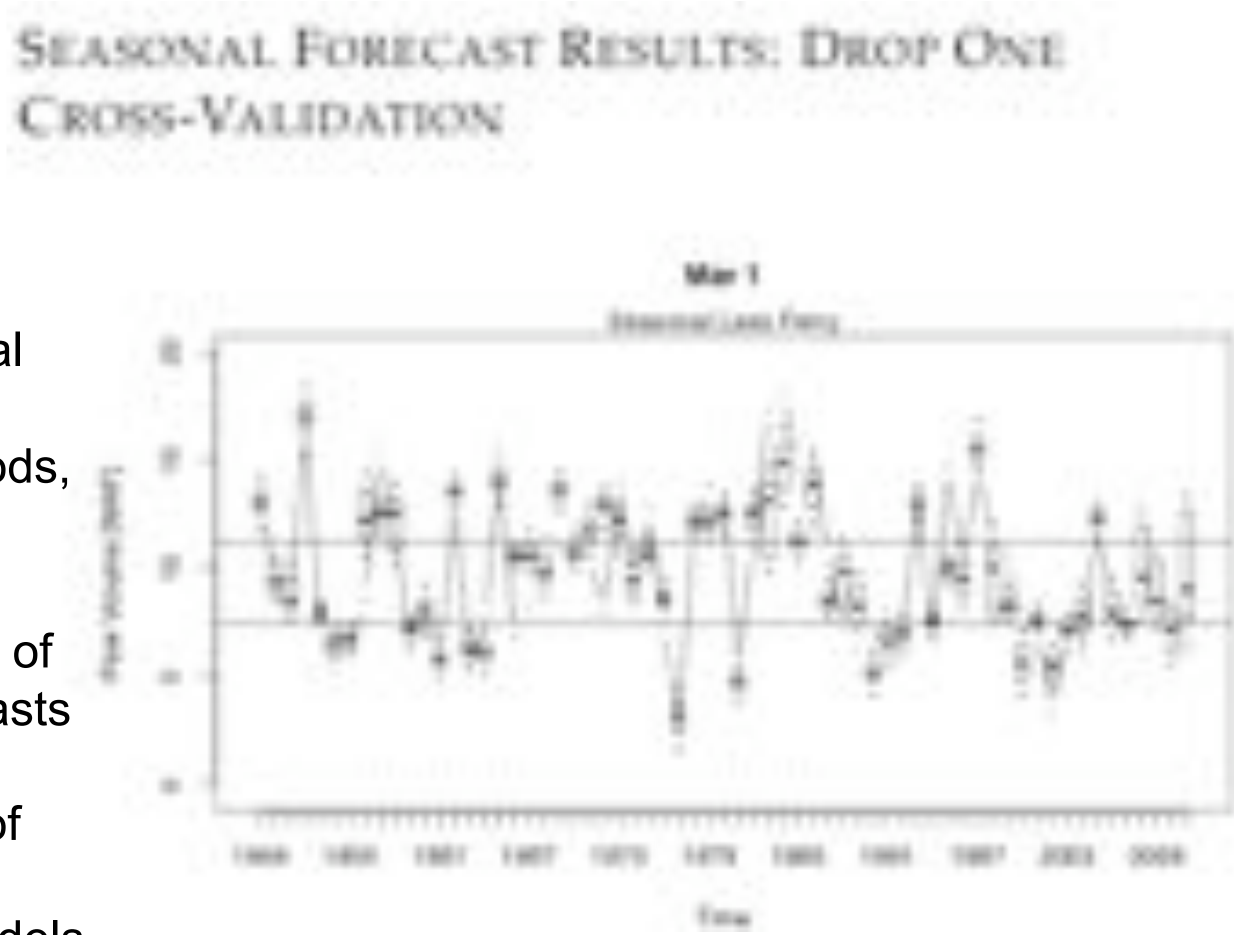






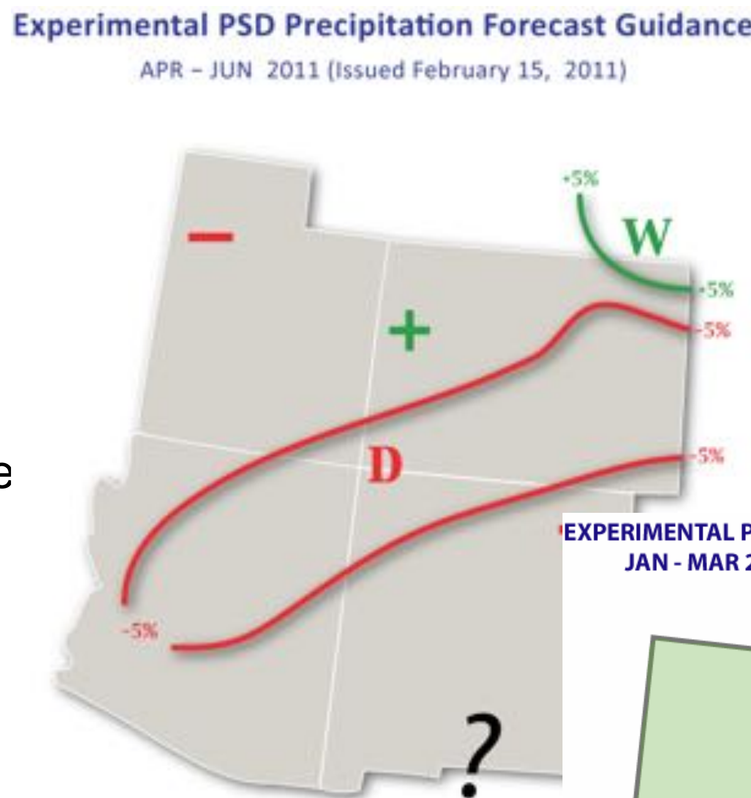
U of Colorado effort: Bracken, Caraway, Rajagopalan

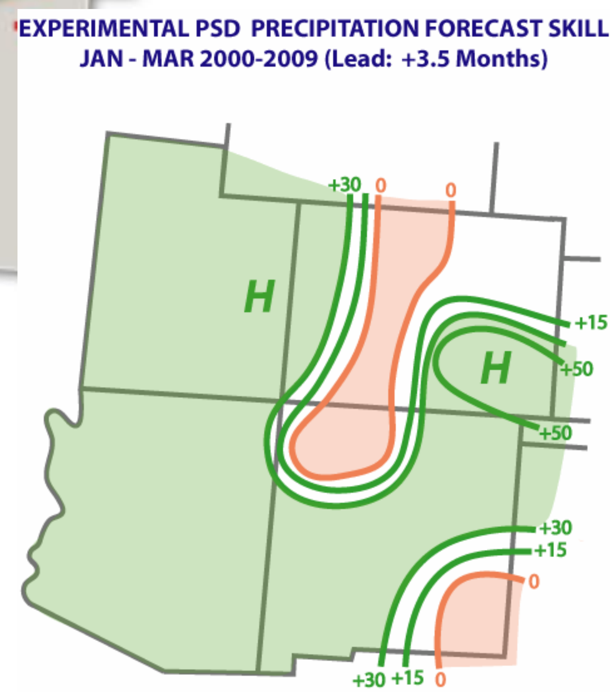
- **Goals**:
  - Improved probabilistic seasonal predictions
  - 2-year predictions for flow
- **Methods**: Various statistical approaches for all goals including time series methods, regression, hidden Markov models
- **Results**: (1) Assessed skill of seasonal streamflow forecasts at various sub basins, (2) Identified “hidden states” of Colorado River time series through hidden Markov models



CIRES effort: Wolter

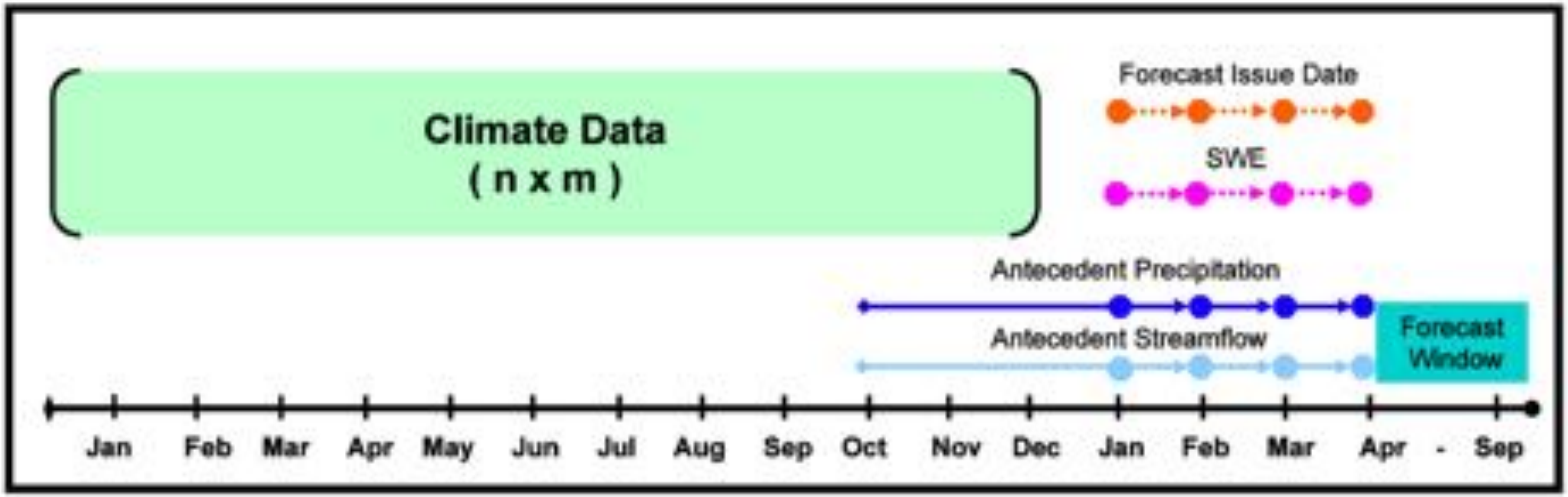
- **Goal**: Seasonal predictions for precipitation, temperature, and eventually streamflow
- **Method**: Stepwise linear regression based on “flavors of ENSO and non-ENSO teleconnections” to gridded time series, streamflow time series, and modified climate division time series
- **Results**: Seasonal predictions dating back to 2000 with some verification





PSU Effort (Moradkhani)

- **Goal**: Seasonal prediction of water supply based on traditional predictors AND climate system information (~20 indices, EOFs, etc.)
- **Method**: Traditional statistical regression-based models are compared with statistical models such as PCR, PCA, PSLR, and Independent Component Analysis (ICA)
- **Results**: Results from the Pacific Northwest compare favorably against official NRCS/NWS coordinated forecasts



USU Effort: Wang and Gillies

- **Goals**: Seasonal prediction of various climate variables
- **Method**: Dynamics-based, region-specific analysis. Apply statistical techniques including principle component – lagged regression to features of climate prediction datasets
- **Results**: Seasonal predictions for climate variables such as SLC inversions, precipitation and temperature tendencies on Utah specific hydroclimate datasets

ST_{30d}(contours) & VP_{30d}(shadings) at 200 mb

CI: 1.5x10^6 m^2 s^{-1}

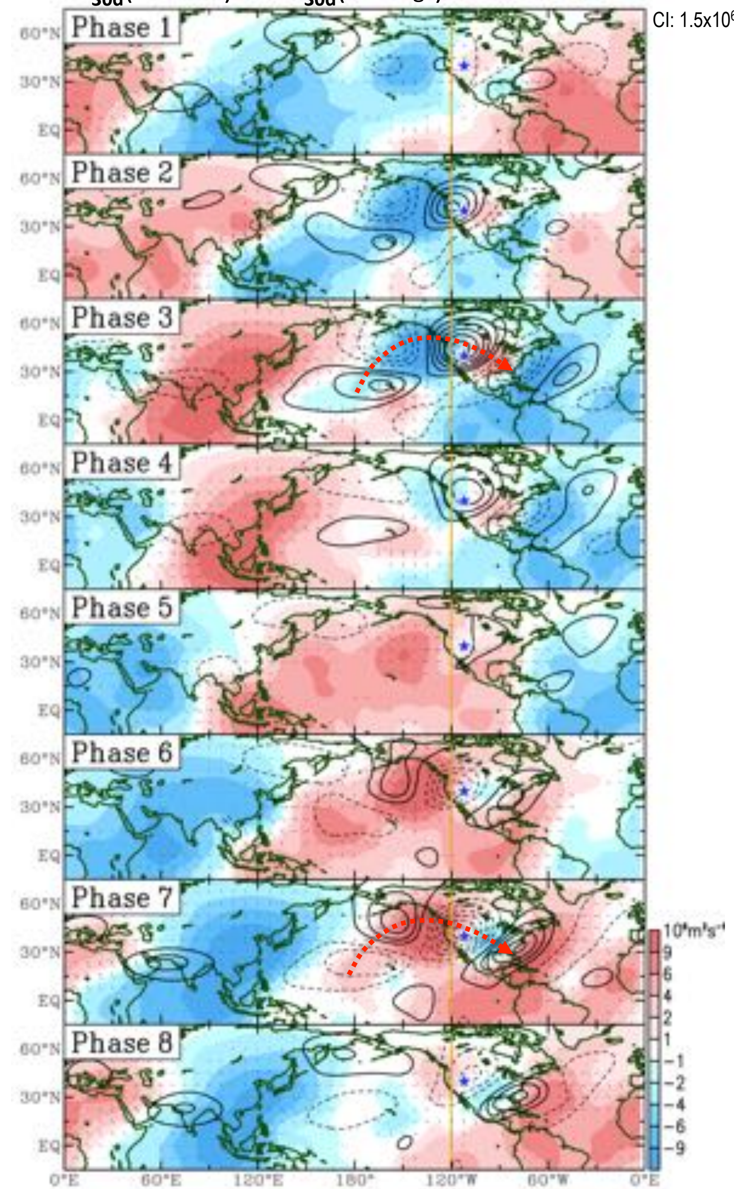


Fig. 3 Eight-phase composites of the 200mb velocity potential (shadings) and streamfunction constructed form the 30-day mode at Salt Lake City. Adopted from Gillies et al. (2010b).

considerations in climate forecast evaluation

Each hydrologic anomaly has a story line. As water year progresses:

•past wx/climate (hydrologic initial conditions) are an increasing part of the plot

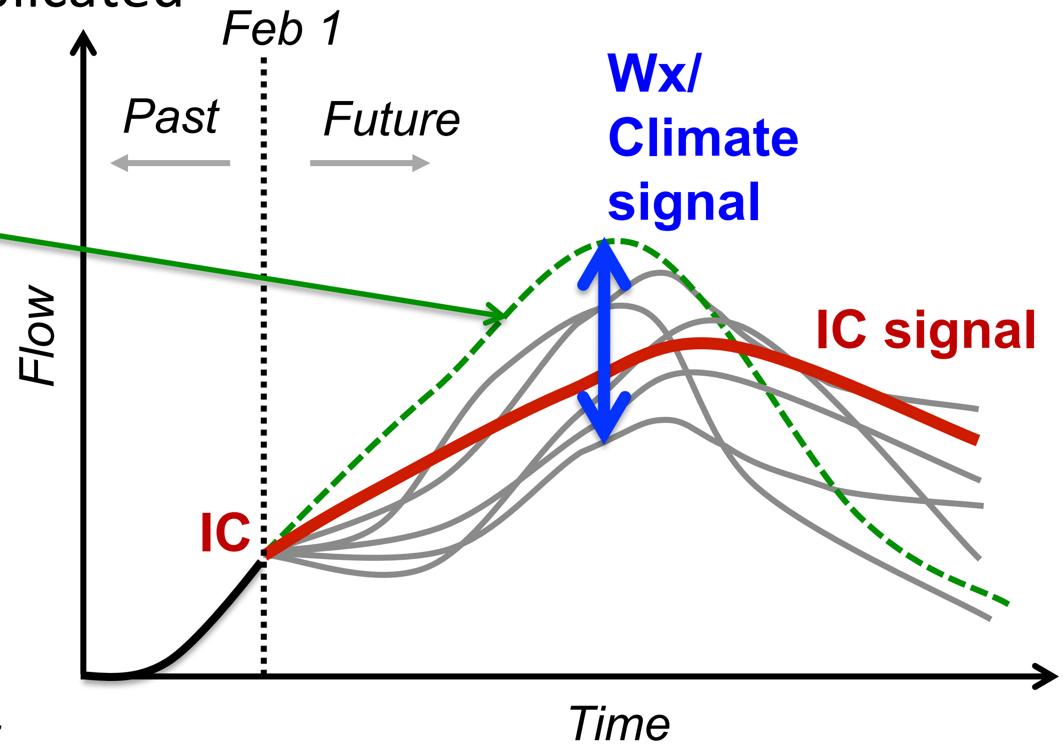
•future climate is a diminishing part of the plot

•extremes often involve pattern persistence …

but can be more complicated

e.g., storyline:

- big storm in Feb
- very wet April
- cool May/June



e.g., Wood & Lettenmaier, 2008 GRL

Hydrology integrates wx/climate patterns

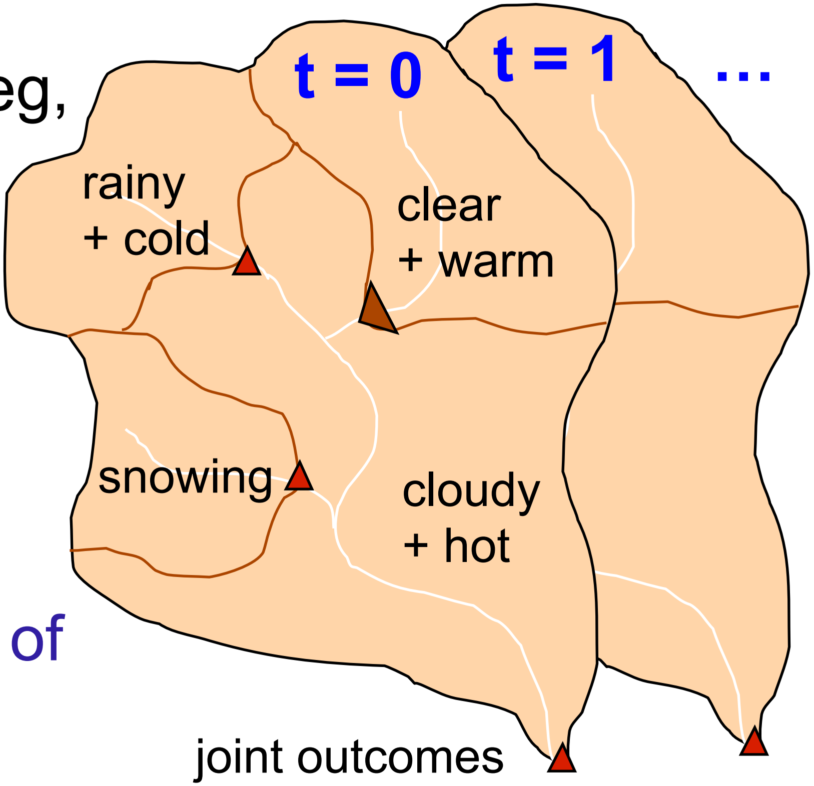
•Spatial relationships across very large areas

- single catchment to river basin

•Temporal sequences compound

- weekly to multi-year

•Multivariate patterns matter too (eg, precip **X** temp)



Thus:

1)it' s hard to measure quality of a climate forecast by a climate metric alone

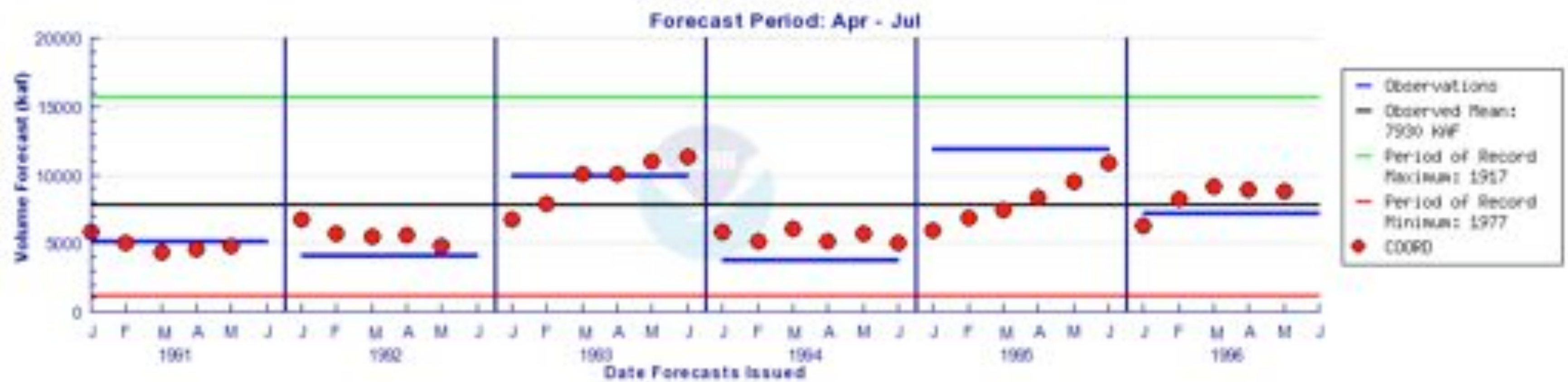
2)*hydrologic metrics* measure quality of the wx/climate patterns that matter

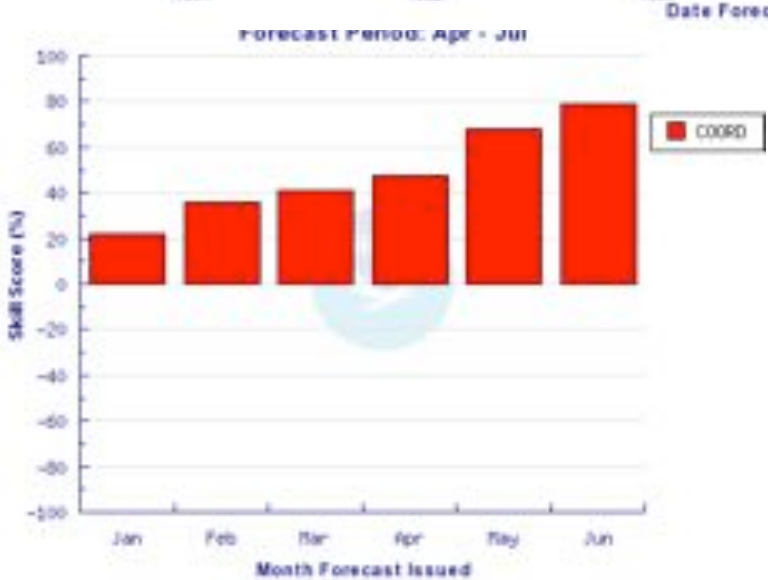
Streamflow Prediction Baselines / Metrics

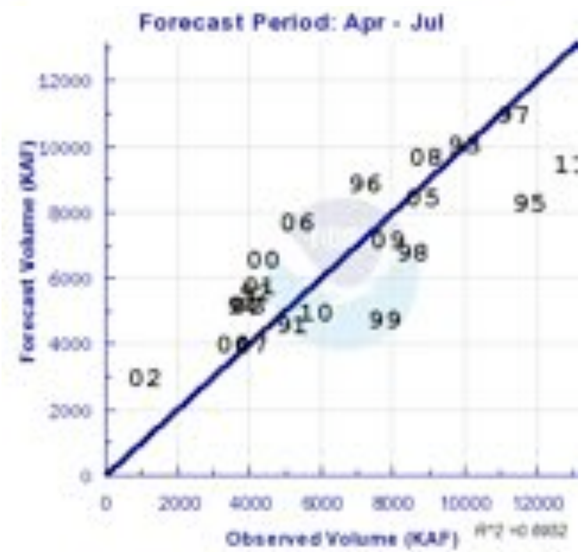
Testbed includes analysis of current approaches

•without climate forecasts, hydrology forecasts still have skill

•Promote evaluation of new techniques *wrt* existing ones for key watersheds







Summary & Next Steps

Summary

- CBRFC is implementing a river-focused climate & flow prediction testbed to make climate research relevant to water management
- Both dynamical and statistical approaches are of interest

Next Steps

- Populate the water-oriented testbed with our own RFC efforts & data
  - e.g., update with CFSv2
- Steer funded research partners toward testbed watersheds
  - Invite others & collaborate in new funding proposals
- Implement promising techniques at the RFC, experimentally
  - observe operation constraints:

    e.g., use only real-time data; use **R** not Matlab…
- Expand water-focused testbed to other regions?

Questions?

andy.wood@noaa.gov

http://en.wikipedia.org/wiki/Lake_Powe