

# RECLAMATION

*Managing Water in the West*

## Erosion of Water Supply Predictability under Climate Change?

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Co-Investigators: Kevin Werner (NWS CBRFC), Donald Laurine (NWS NWRFC), David Garen (NRCS NWCC)



U.S. Department of the Interior  
Bureau of Reclamation

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# Project Team and Support

- Investigators
  - Reclamation (L. Brekke, T. Pruitt)
  - NRCS National Water and Climate Center (D. Garen)
  - NWS CBRFC (K. Werner, Craig Peterson),
  - NWS NWRFC (D. Laurine, Ray M)
- Collaborators (methods review, model/data sharing)
  - NWS MBRFC (G. Shalk)
  - NWS CNRFC (P. Fickenscher)
  - USACE Portland District
  - Bonneville Power Administration
- Support
  - Reclamation, NRCS, and NWS RFCs

# Context

- Water Supply Forecasts = spring-summer runoff volume forecasts for basins throughout the western U.S., issued by NRCS and NWS
- The forecasts guide reservoir operations scheduling.
  - E.g., monthly schedules of release volumes for multiple objectives
- Attributes
  - Forecast Periods: Apr-Jul, other spring-summer periods
  - Issue Months: Jan, Feb, Mar, Apr ...
  - ~Predictors at time of Issue:
    - P: antecedent precipitation (~October-to-date)
    - SWE: Snow water equivalent (~at time of Issue)
  - Forecast Models (statistical type)
    - Regression equation: Runoff modeled as function of P and SWE
    - Calibrated to reflect historical relationships

# Questions

- Does climate change with warming lead to reductions in water supply predictability?
  - Do model calibration and validation characteristics change?
  - If yes, at what rate?
- What are the ramifications for longer-term planning? (*anticipating the future...*)
- What forecast model-maintenance procedures might be applied to minimize reductions in predictability?

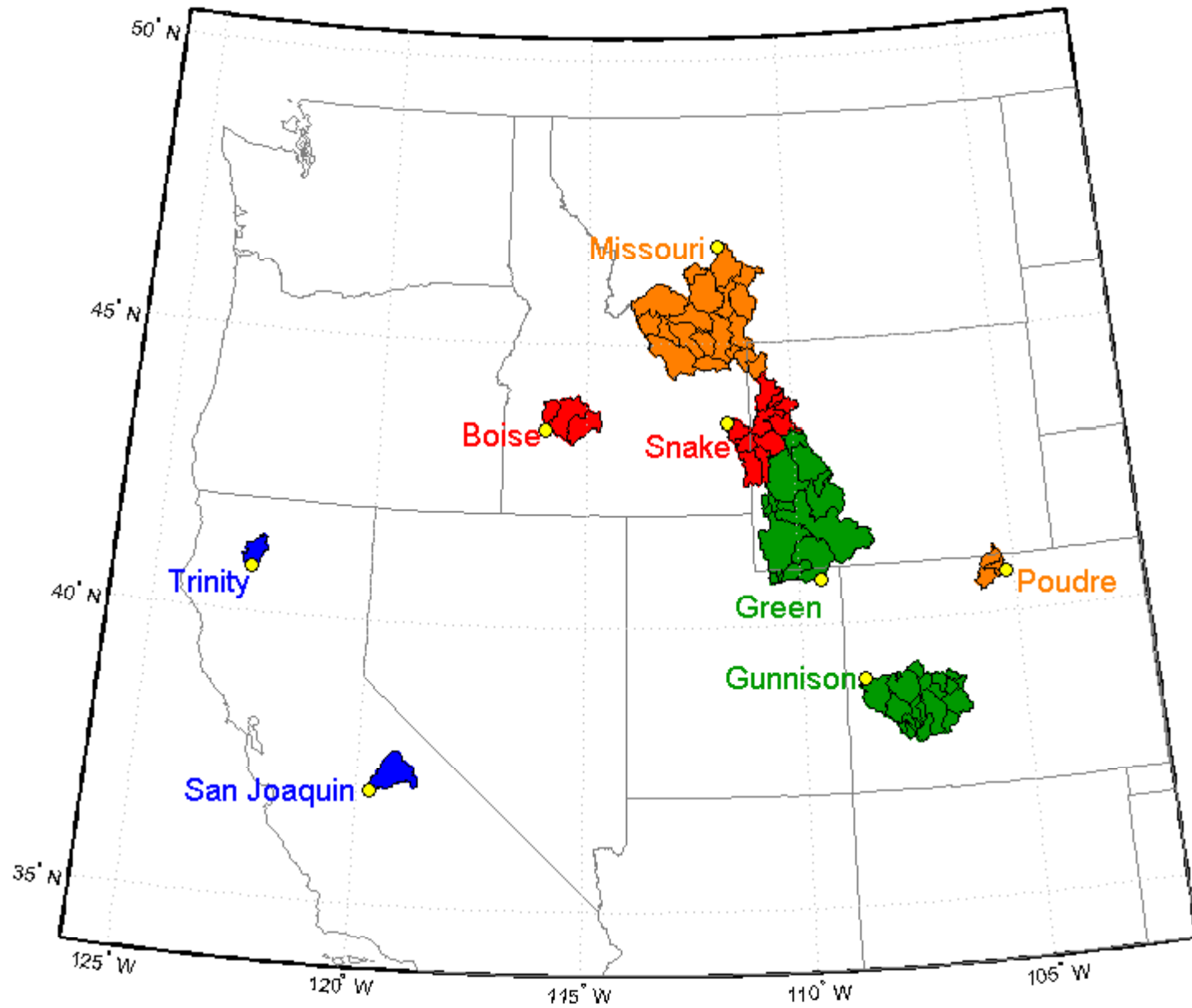
# Research Approach

1. Select Ensemble of **Climate Projections**, 1950-2099.
2. Translate into Ensemble of Basin **Hydroclimate Projections** (**P**, **SWE**, **Runoff**), 1950-2099
  - process-based hydrologic simulation modeling
3. Make **Forecast Projections**, 1981-2099
  - build forecast models within hydroclimate projections
  - update forecast models decadally, similar to NRCS procedures
4. Evaluate validation forecast skill through time as climate changes.
5. Explore ways to preserve skill (e.g., other predictors, different update frequency, etc). Evaluate by re-doing (3) and (4).

# Starting Points

- Study Basins
- Climate Projections Data
- Hydrologic Simulation Model & Application
- Water Supply Forecast Model

# Case Study Basins

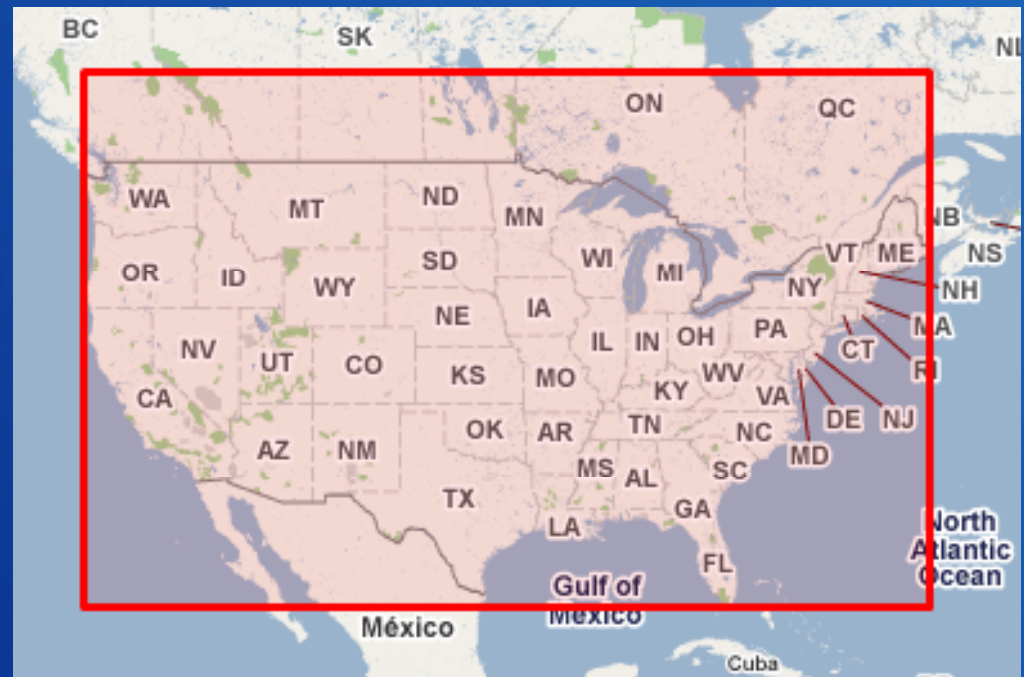


# Climate Projections (Bias-corrected, Spatially Downscaled)

[http://gdo-dcp.ucllnl.org/downscaled\\_cmip3\\_projections/](http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections/)

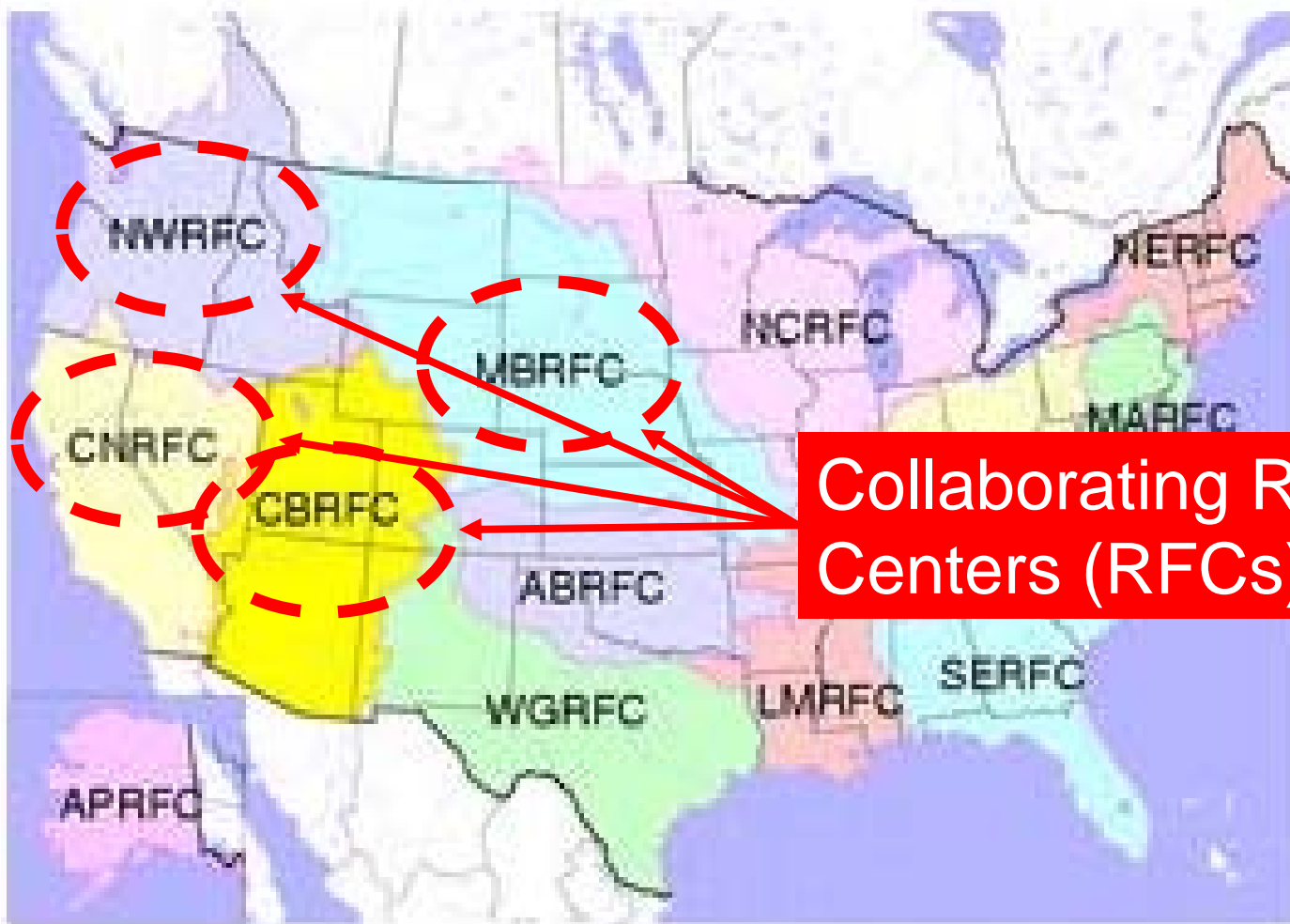
**google “cmip3 projections”, first link**

- 112 Projections
  - 16 models, 3 emission scenarios, and multiple initializations for model-emissions combination
- Variables:
  - Precipitation Rate (mm/day)
  - Mean Daily Temperature (°C)
- Temporal Coverage and Resolution
  - 1950-2099, monthly
- Spatial Coverage and Resolution
  - Contiguous U.S., 1/8° (~12km x 12 km)
- Developers
  - Reclamation, Santa Clara University (Ed Maurer), LLNL



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# Hydrologic Model Source: National Weather Service



Collaborating River Forecast  
Centers (RFCs)

MATION

Temperature drives  
Snow simulation...

# SacSMA/Snow17 Schematic

## SNOW ACCUMULATION AND ABLATION MODEL (SNOW-17)

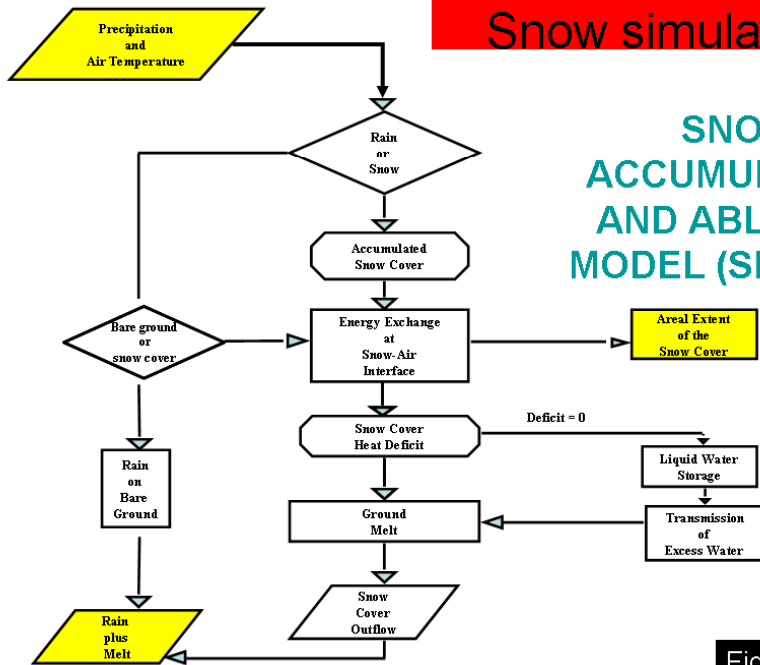


Fig. K. Werner

## Rainfall-Runoff Model

## Sacramento Soil Moisture Accounting Model (SAC-SMA)

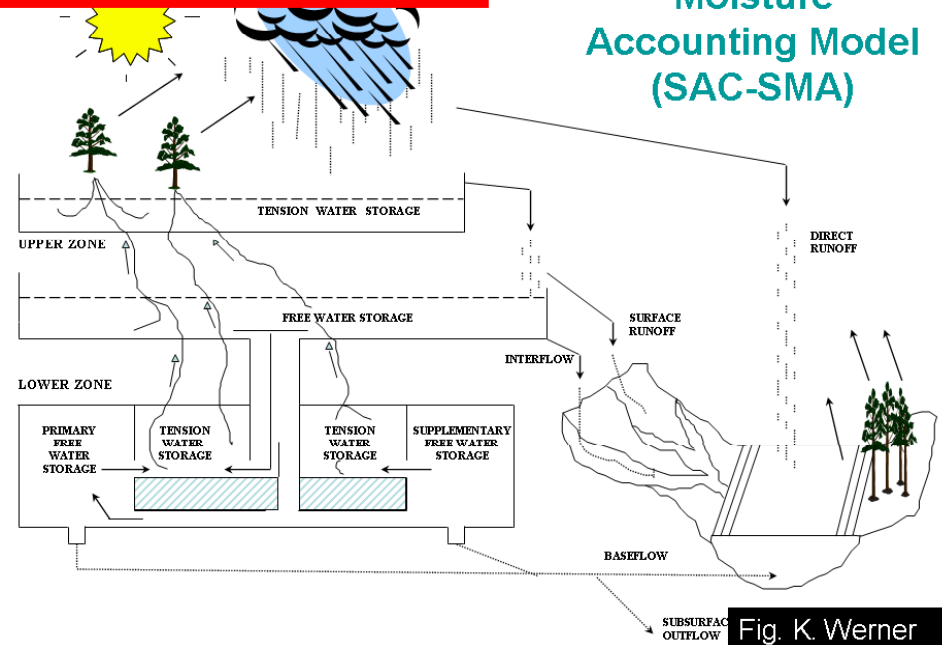


Fig. K. Werner

# Applying SacSMA/Snow17 to make Hydroclimate Projections

- Single hydrologic simulation for each projection
  - time-developing, inherits projection's variability
  - contrasts from USGS' annual indexing series of 12-year step-change analyses reflecting change in period climate at each step
- Weather Forcings (T and P)
  - require 6-hourly, mean-area
  - followed Wood et al. 2002
    - procedure for resampling/scaling observed 6-hourly sequences
    - produces forcings that are consistent with monthly projection time series
- PET adjustment? Used Hamon & moving-climatological adjustment
  - Details upon request...
- Saved Simulation Variables
  - Water Balance input: T, P, PET
  - Water Storage: SWE, soil moisture
  - Water Balance output: Runoff, actual ET

# Water Supply Forecast Model

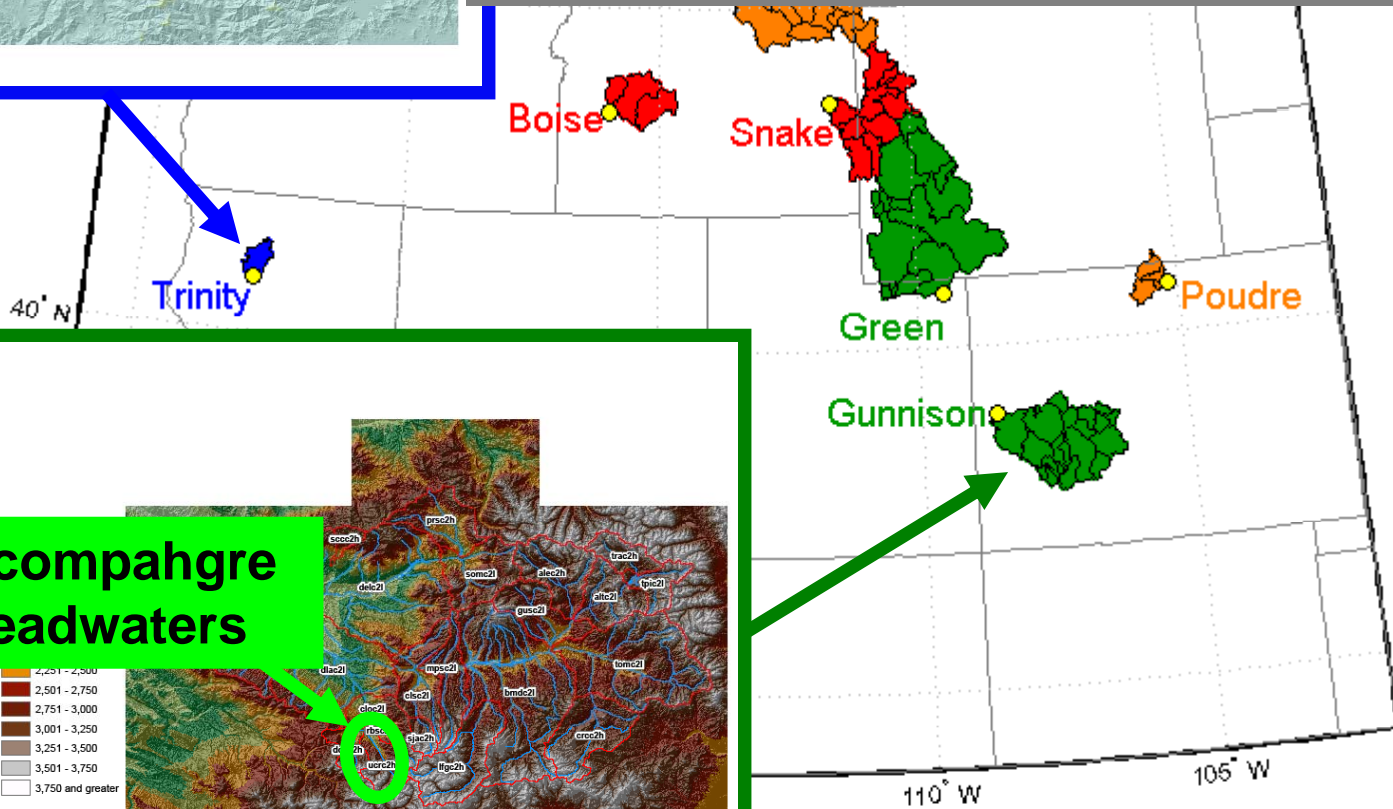
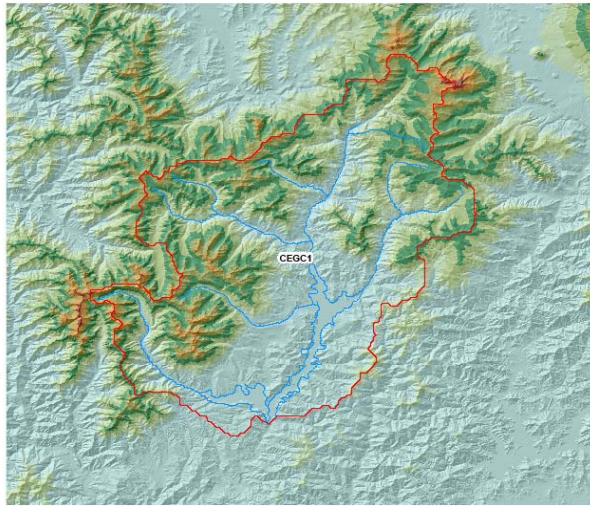
- Statistical Method similar to that used by NRCS & NWS
  - PC-Regression
  - AMJJ Runoff predicted by:
    - Snowpack at Time of Forecast
    - Precipitation since ~October
    - Data blended using PCA → candidate predictors
  - Regression Forecast Models built for multiple issue dates
    - Jan 1<sup>st</sup>, Feb 1<sup>st</sup>, Mar 1<sup>st</sup>, Apr 1<sup>st</sup>
- Our Application has minor differences...
  - We use mean-area predictors, not point (station) predictors.
  - We use a preset predictor season for precipitation, rather than search for best season as NRCS would do.

# Status

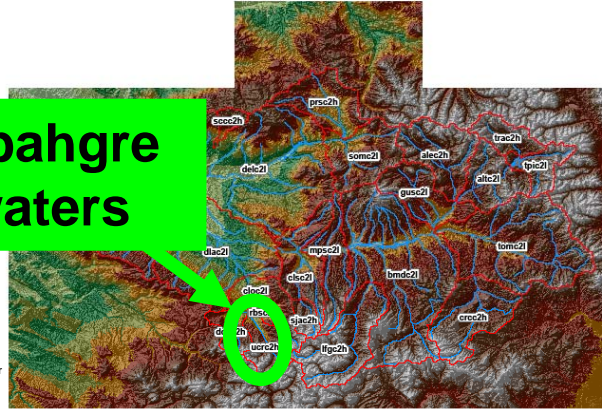
- Climate Projections Selections
  - Considered projection subsets from the archive mentioned
  - Eventually opted to look at all 112 projections in the archive
    - (looking at 10 vs 100 didn't matter, except for computation time)
- Basin Hydroclimate Projections
- Water Supply Forecast Modeling

# Status: Hydroclimate Projections – Two Examples

Elevation (m)  
<VALUE>  
0 - 1,250  
1,251 - 1,500  
1,501 - 1,750  
1,751 - 2,000  
2,001 - 2,250  
2,251 - 2,500  
2,501 - 2,750  
2,751 - 3,000  
3,001 - 3,250  
3,251 - 3,500  
3,501 - 3,750  
3,750 and greater

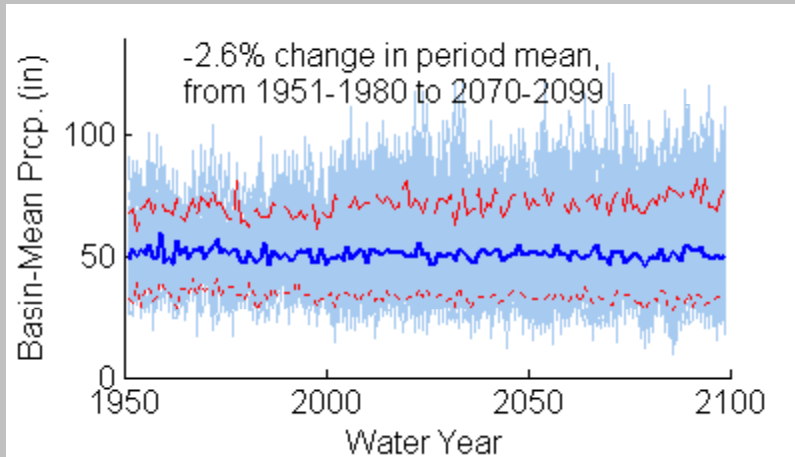
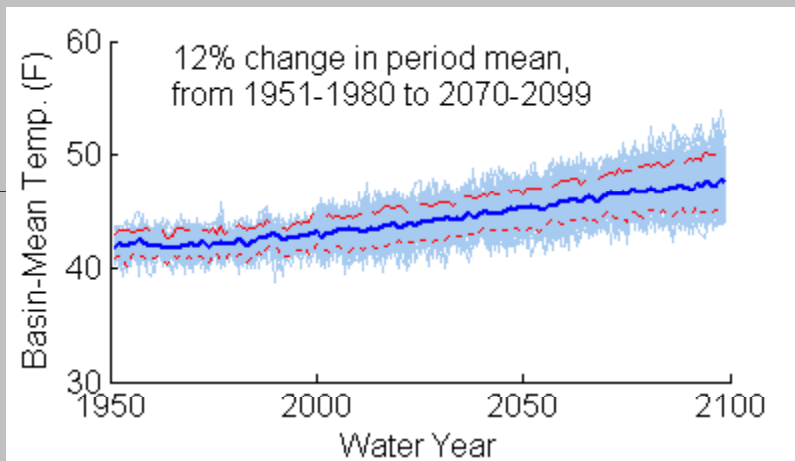


**Uncompahgre  
Headwaters**

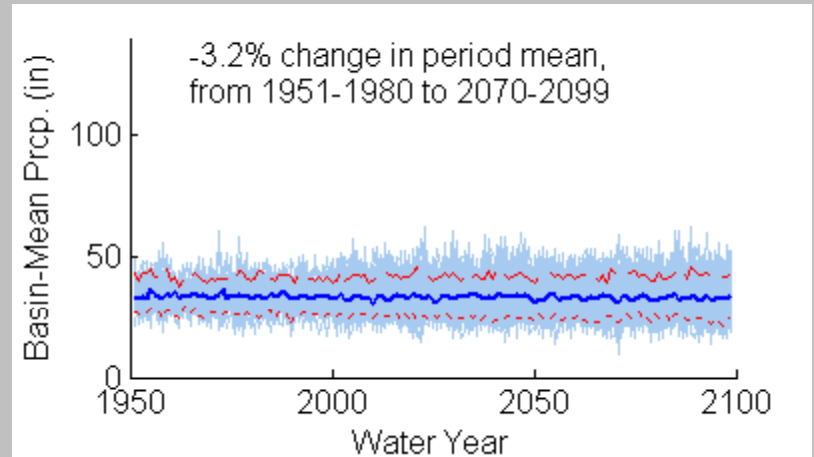
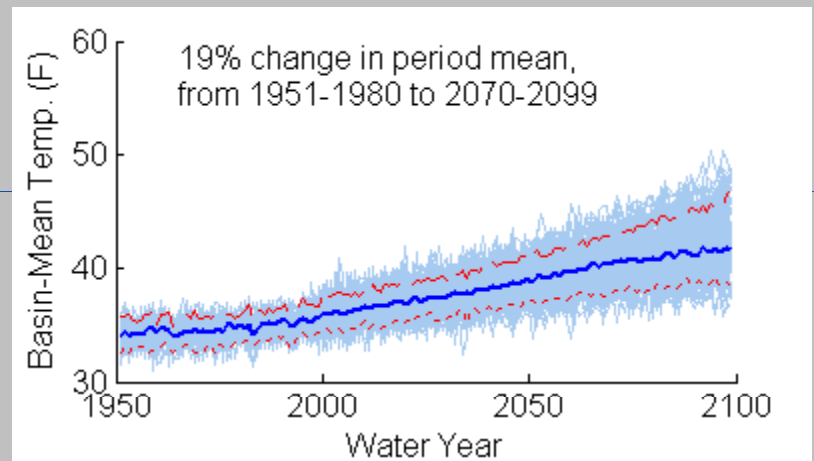


# Annual Temperature and Precipitation

## Trinity

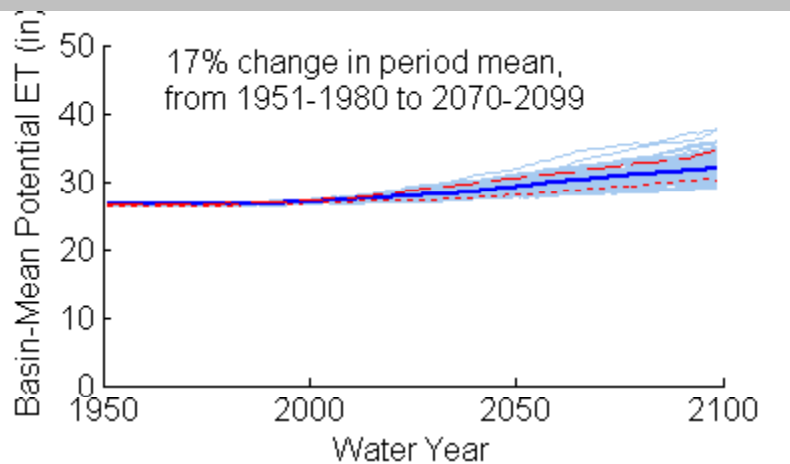


## Uncompahgre

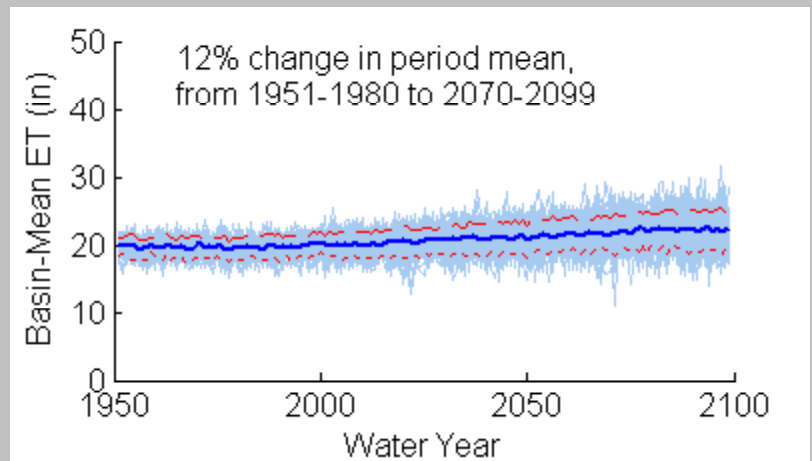
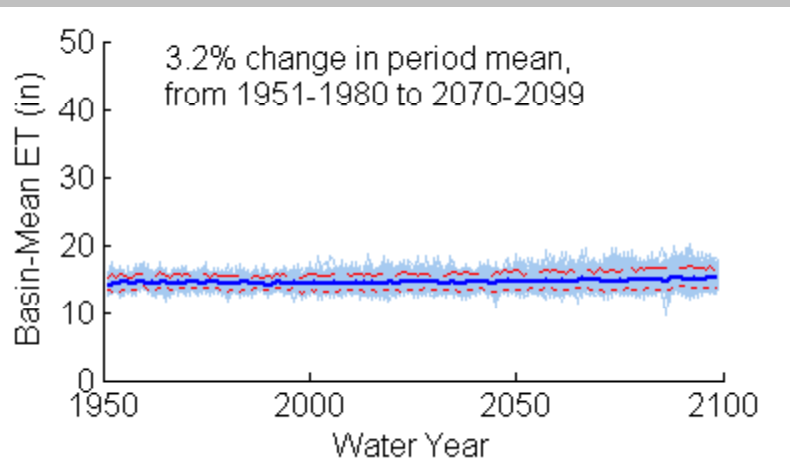
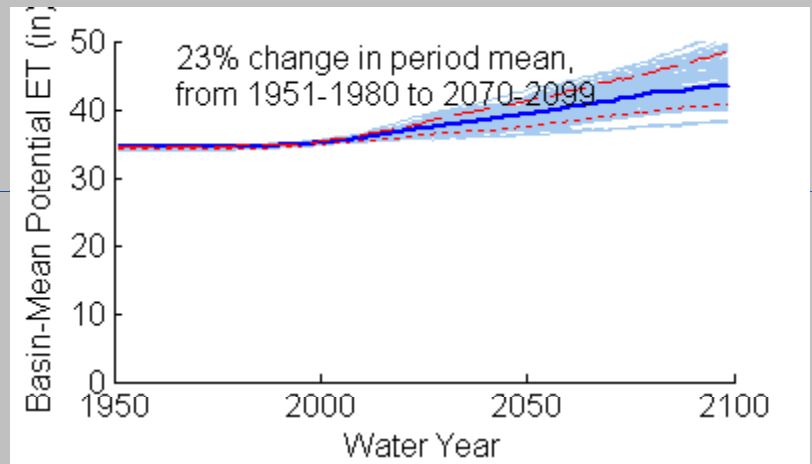


# Annual Potential and Actual ET

Trinity

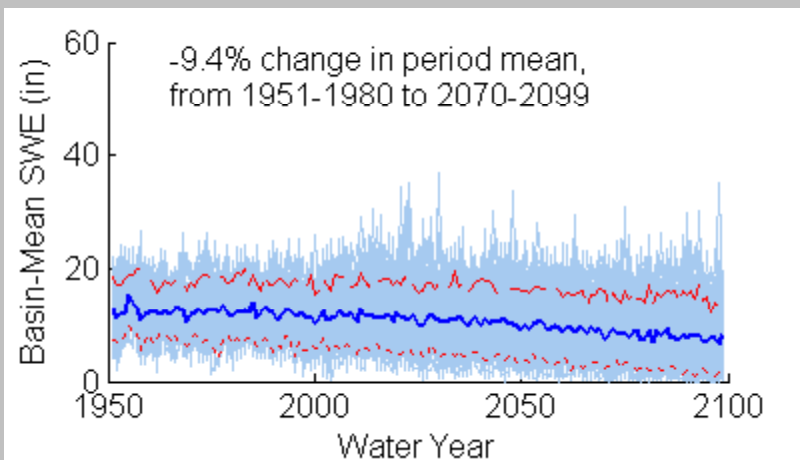
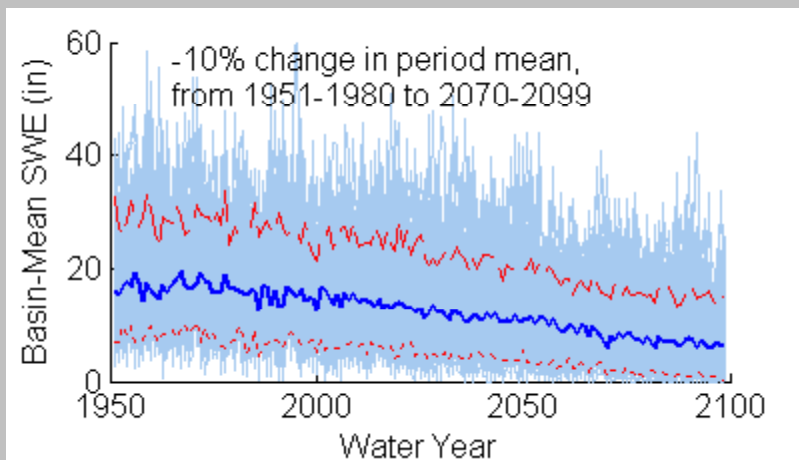
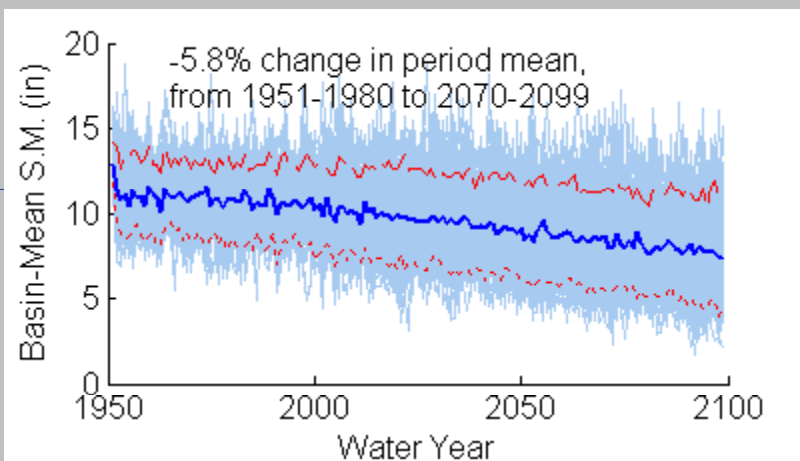
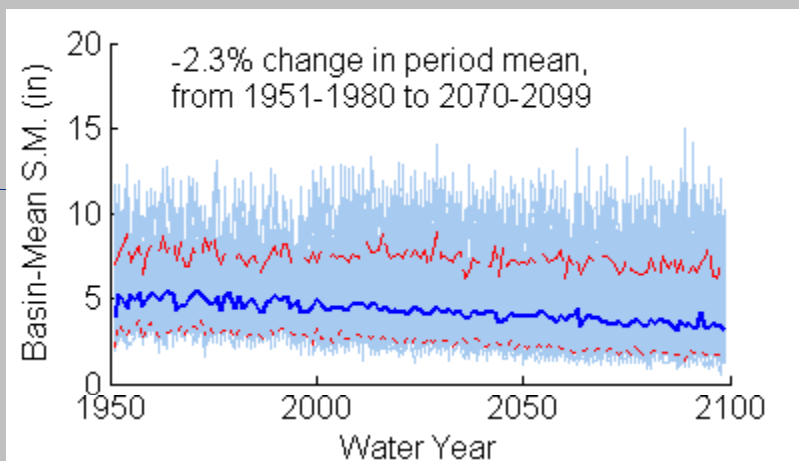


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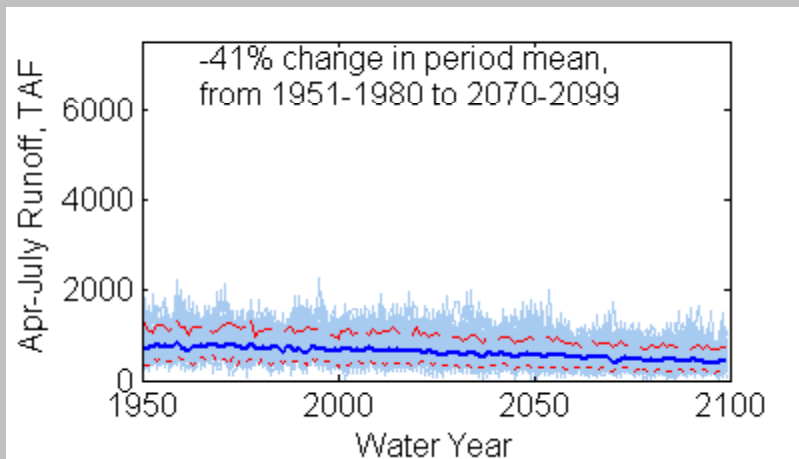
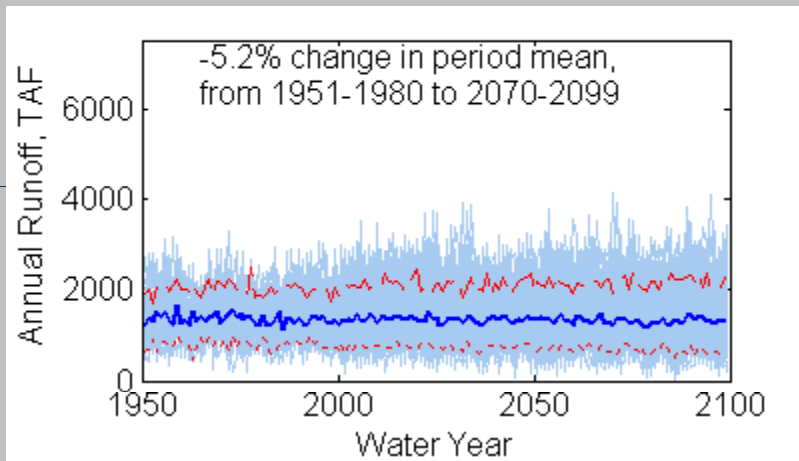
# Nov. 1<sup>st</sup> Soil Moisture & Apr. 1<sup>st</sup> SWE

Trinity

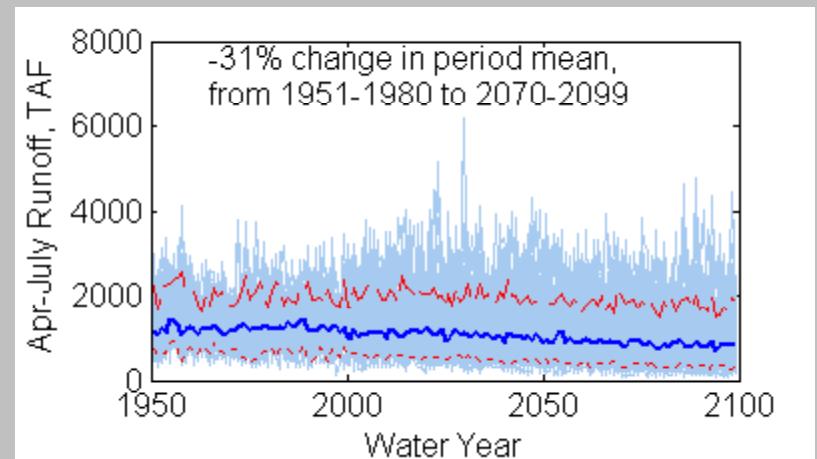
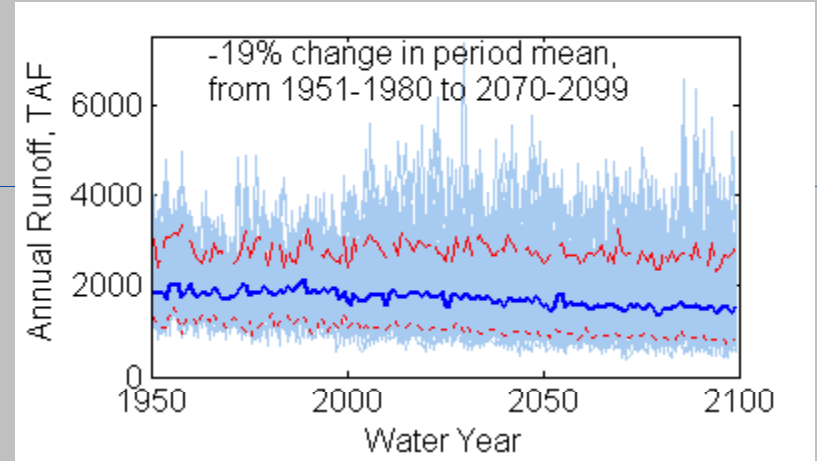


# Annual and April-July Runoff

Trinity



Uncompahgre



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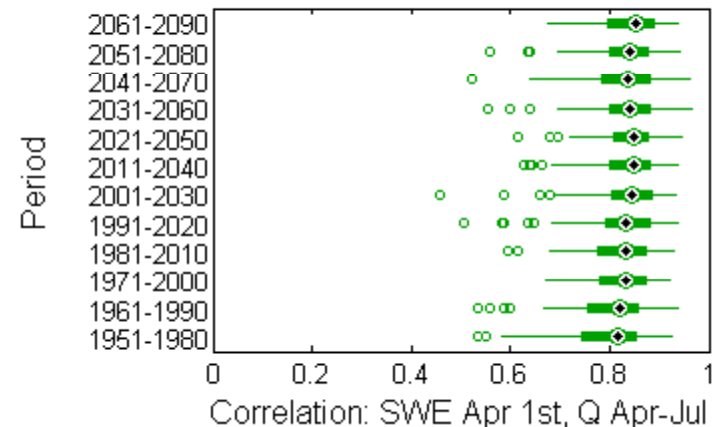
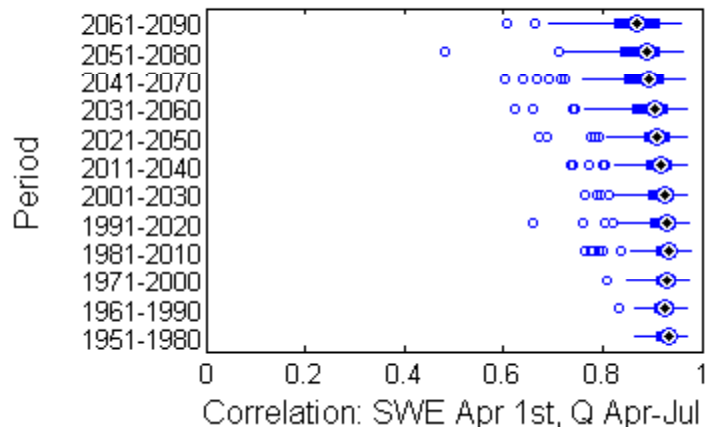
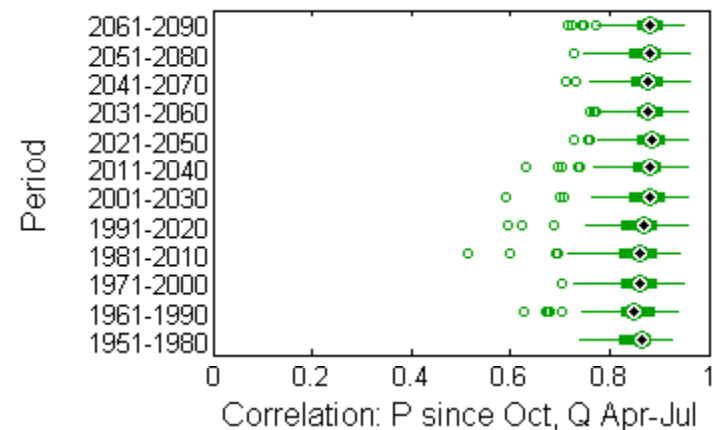
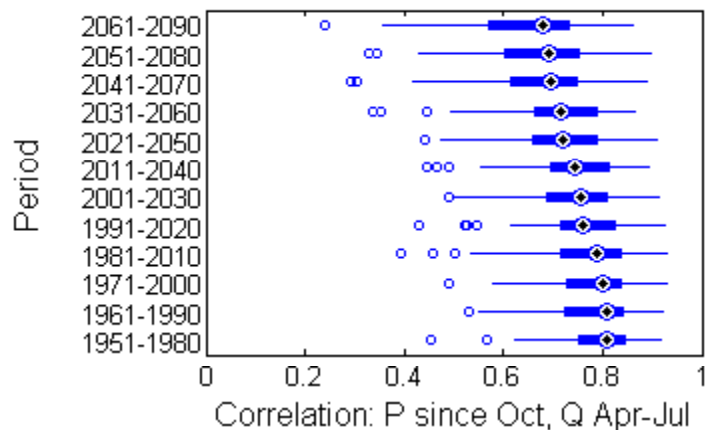
## Water Supply Forecasting through time

- Continue with our Two Examples...
  - Trinity: lower elevation
  - Uncompahgre: higher elevation
- Seasonal Correlations (preliminaries)
  - Two seasonal relationships:  $Q_{AMJJ}$  with either  $P_{Oct-Mar}$  or  $SWE_{April\ 1st}$
  - twelve 30-year periods (1951-1980, 1961-1990,... 2061-2090)
  - Focus: period-correlation through time
- Statistical Forecast Models – calibrated for Apr 1<sup>st</sup> issue
  - Model:  $Q_{AMJJ} = \text{function of } P_{Oct-Mar} \text{ and } SWE_{April\ 1st}$ , where:
    - PCA applied to  $P_{Oct-Mar}$  and  $SWE_{April\ 1st}$  → candidate predictors
    - stepwise regression on candidate predictors
  - twelve 30-year periods (1951-1980, 1961-1990,... 2061-2090)
  - Focus: calibration  $r^2$  and RMSE through time

# Correlations with Runoff, April-July: decadal-moving 30-year periods

Trinity

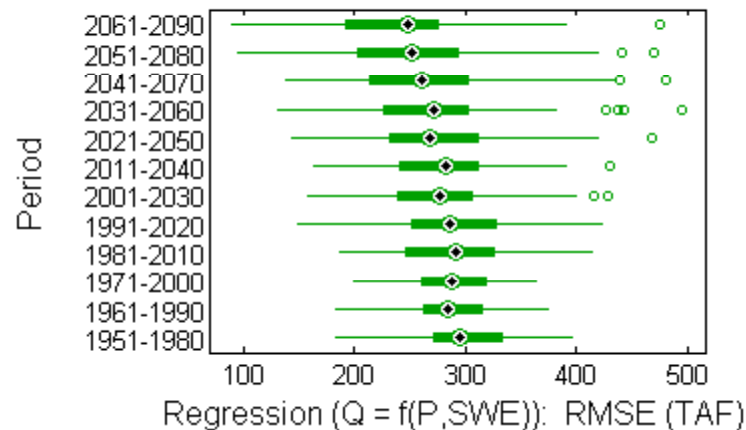
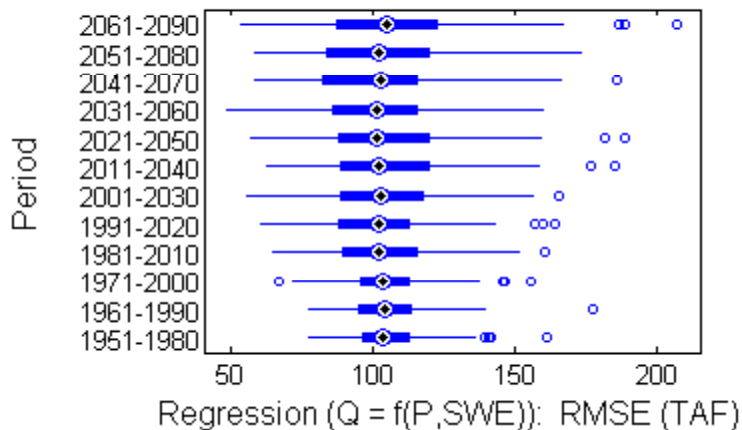
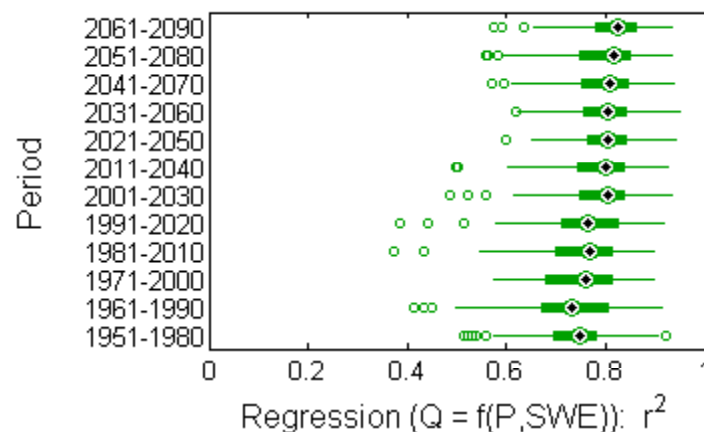
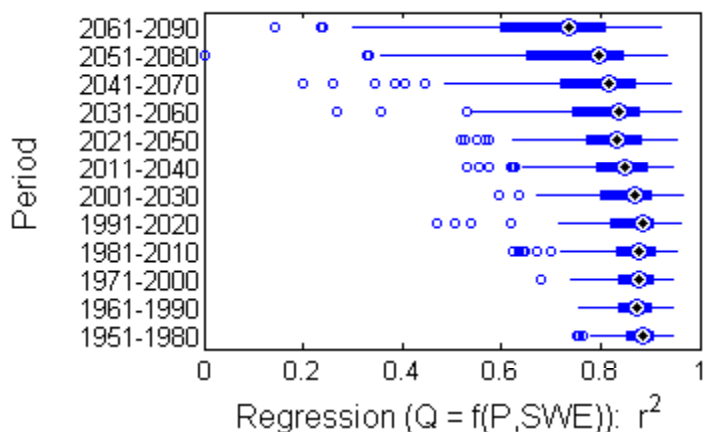
Uncompahgre



# Regression r2 and RMSE: decadal-moving 30-year periods

Trinity

Uncompahgre



# Summary

- We're exploring how climate warming might affect water supply predictability and at what rate.
- We're interested in what that implies about forecast portrayal in longer-term planning and forecast usage in contemporary operations.
- Project completion due Sept 2009 (report ~Dec 2009?)

# Questions?

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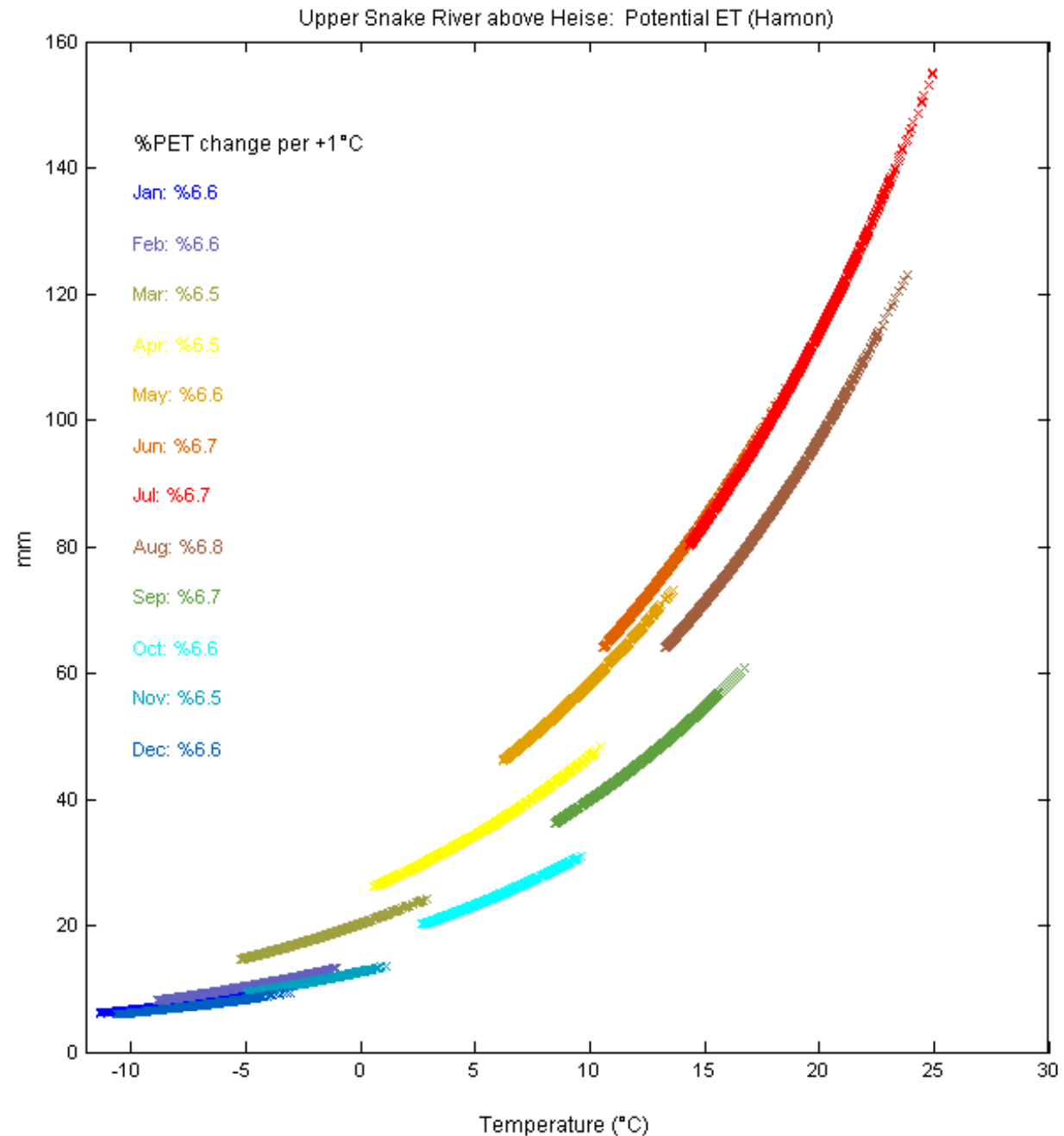
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# Sensitivity of PET to Temperature Change

Plot shows PET sensitivity to change in T, roughly +6.5% per degC, based on Hamon formula.

Clearly, PET is sensitive to warming.

*Different formulas show different sensitivity (e.g., UW NOAH LSM computed PET, using Penman, shows roughly +2 to +3% per degC).*



# Status: Climate Projection Selection

## Decision: Use all 112 Projections

-- basin: *Upper Snake  
abv Heise*

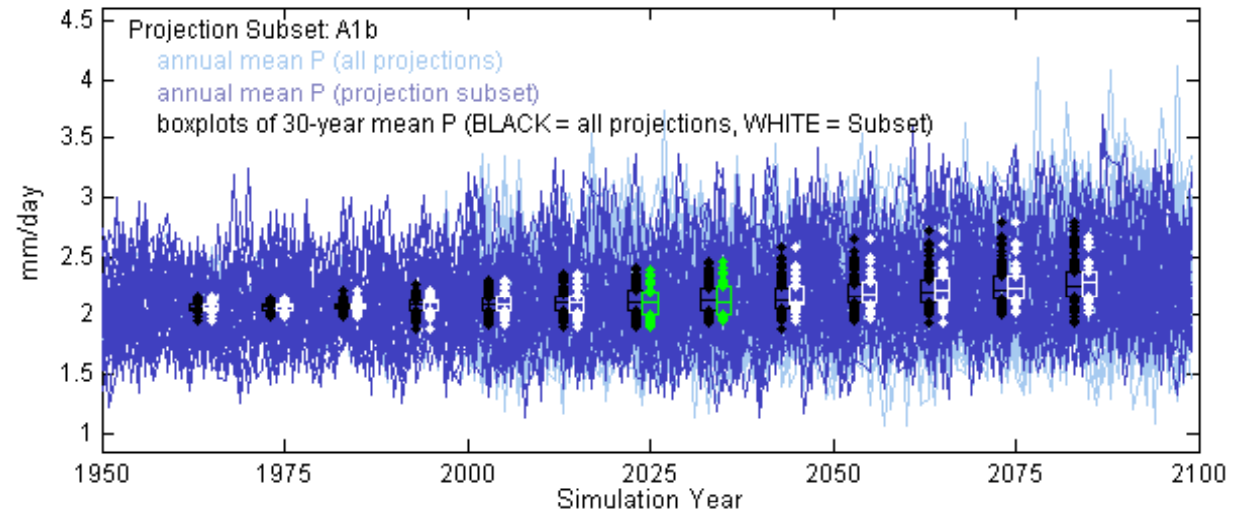
-- annual projections,  
1950-2099.

-- boxplots: tracking  
spread of 30-year,  
decadal moving

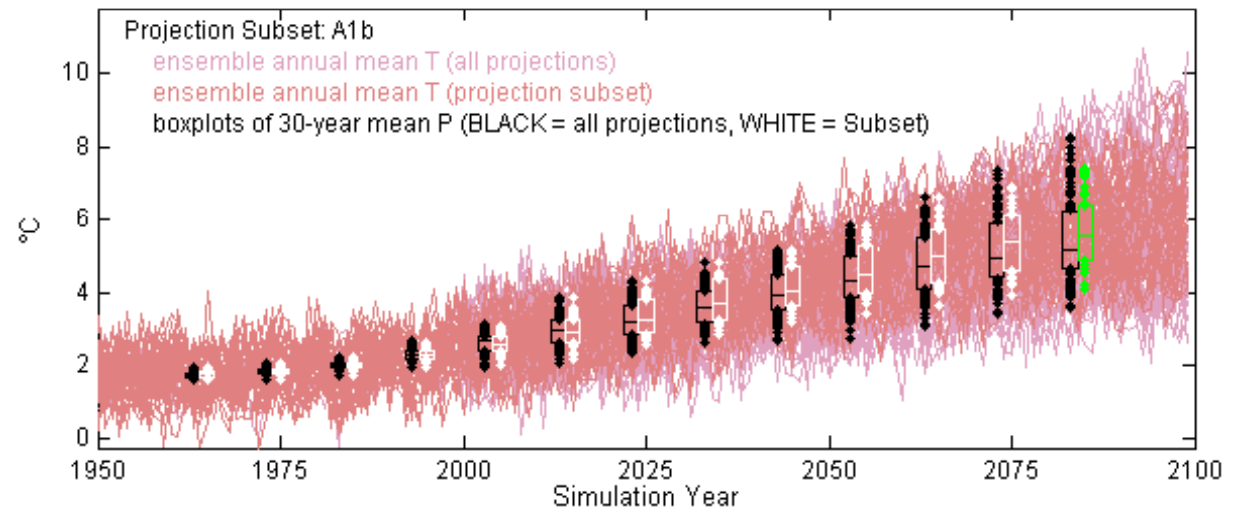
-- black vs white boxplots:  
All vs A1b

-- green boxplots: periods  
when All vs A1b showed  
statistical difference

### Upper Snake River above Heise: Precipitation



### Upper Snake River above Heise: Temperature



# Adjusting PET in SacSMA

- PET is an input to SacSMA.
- RFCs calibrated these applications with the following treatment of PET.
  - Climatological PET: annually repeating mean-monthly pattern
    - basis: NOAA Farnsworth atlas
- In our study, we need to relate time-developing “climatological T” to “climatological PET” in the SacSMA simulation.
- Use Hamon to define PET as  $f(T)$ . Apply annually, 1981-2099, using moving retrospective 30-year period.