A Post-Processor for Hydrologic Ensemble Forecast Products

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Presentation to
DOH Workshop

July 16, 2008
Silver Spring

Elements of a Hydrologic Ensemble Prediction System

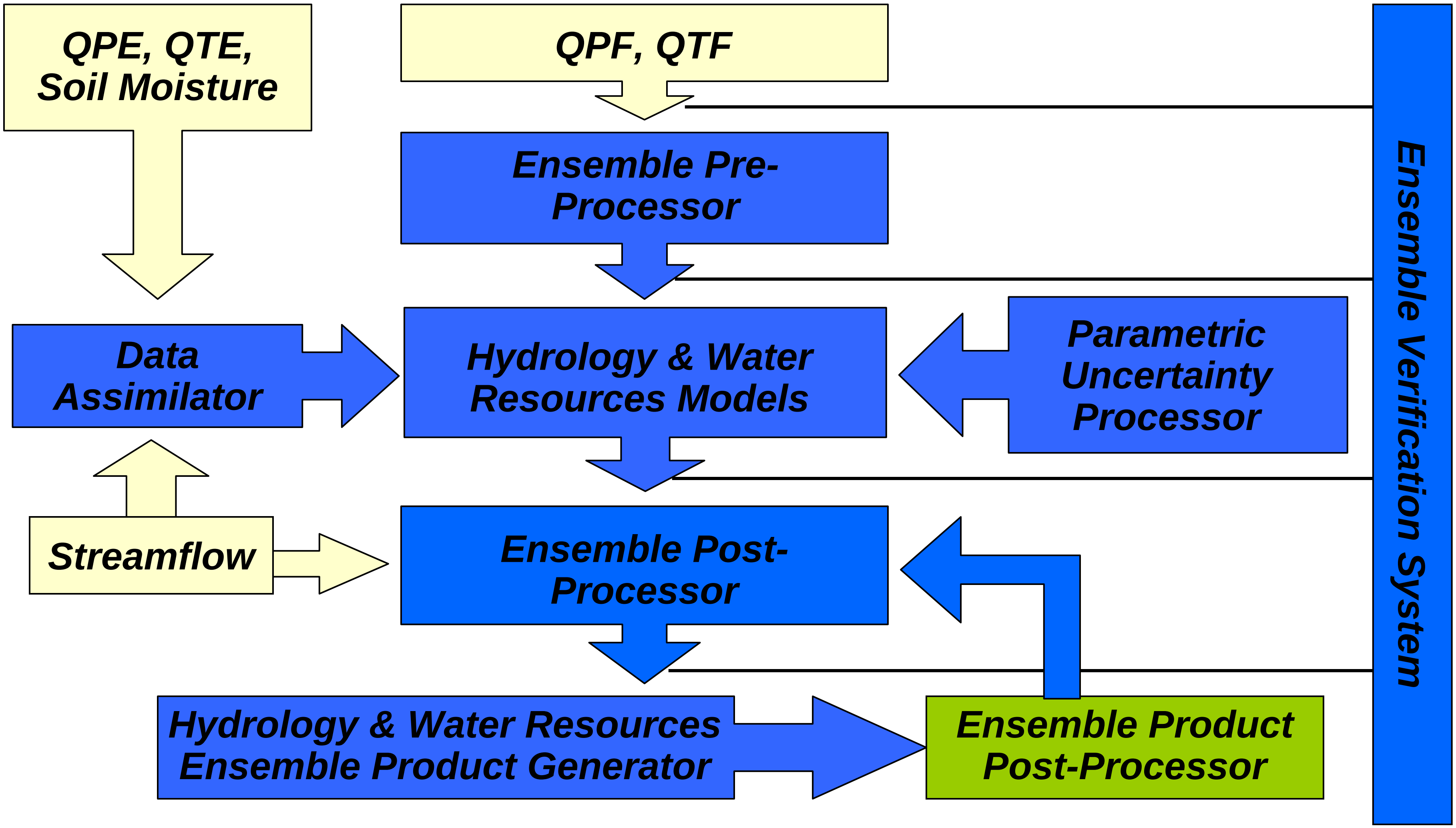
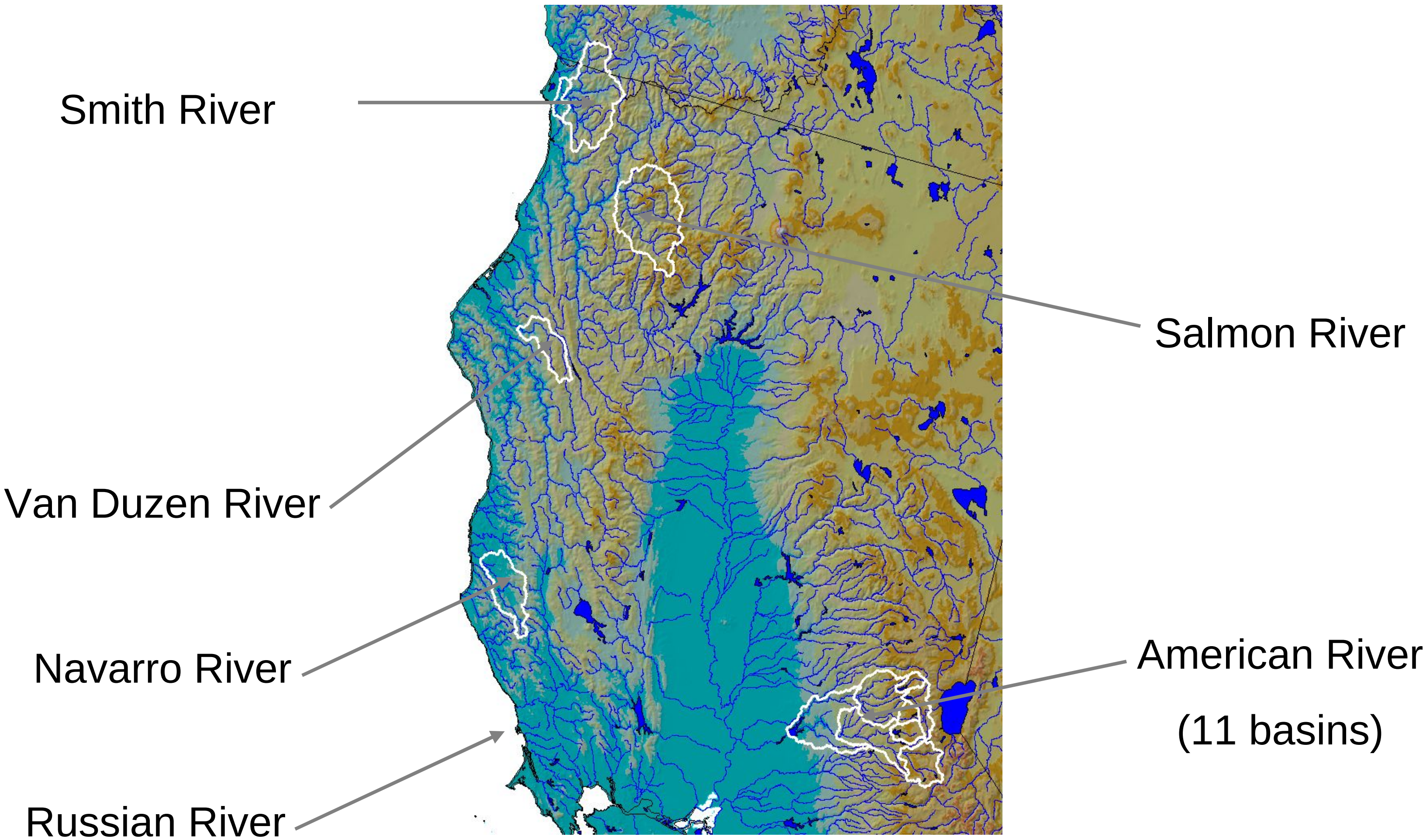
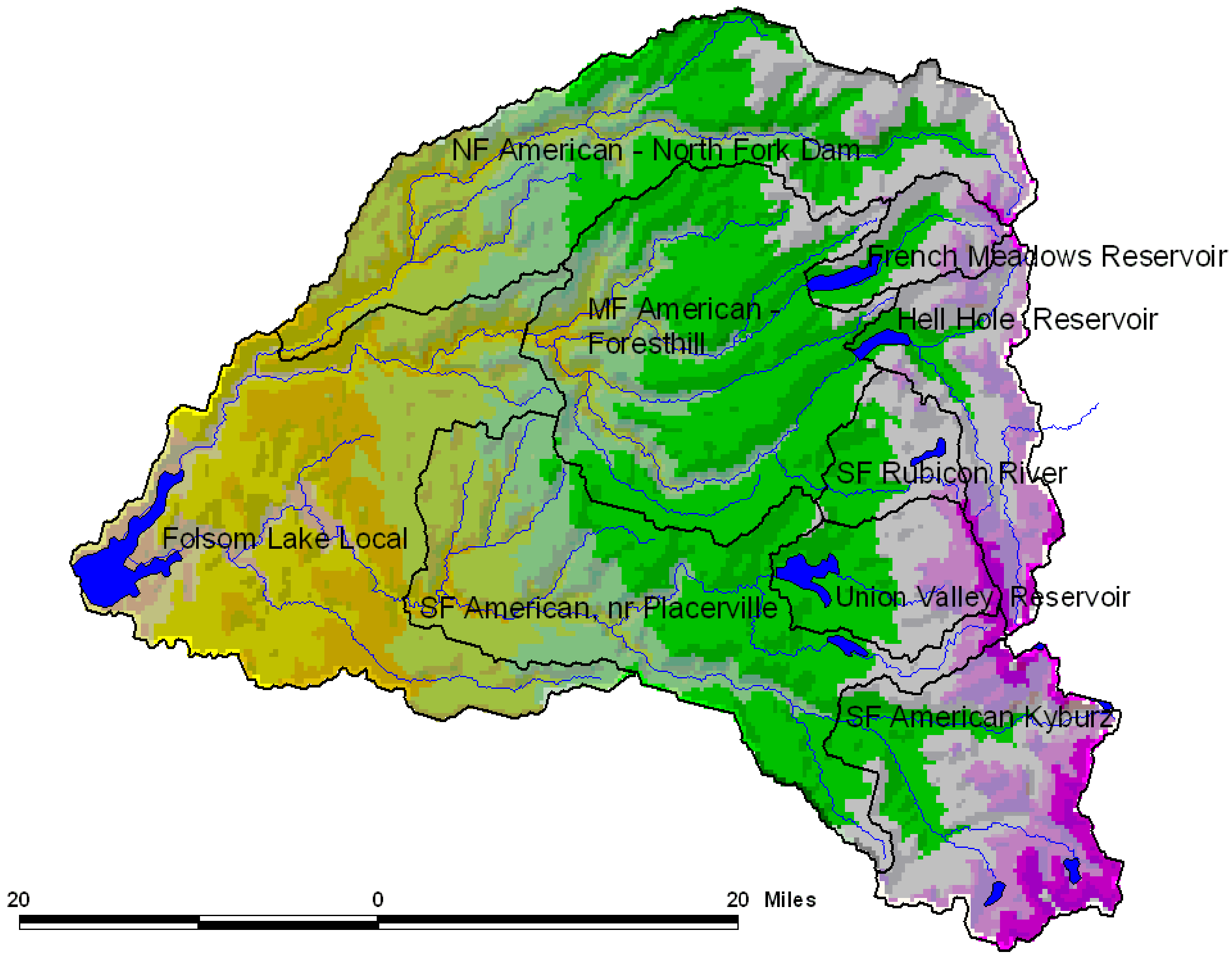


Fig 1

CNRFC Ensemble Prototype Locations



American Watershed Model

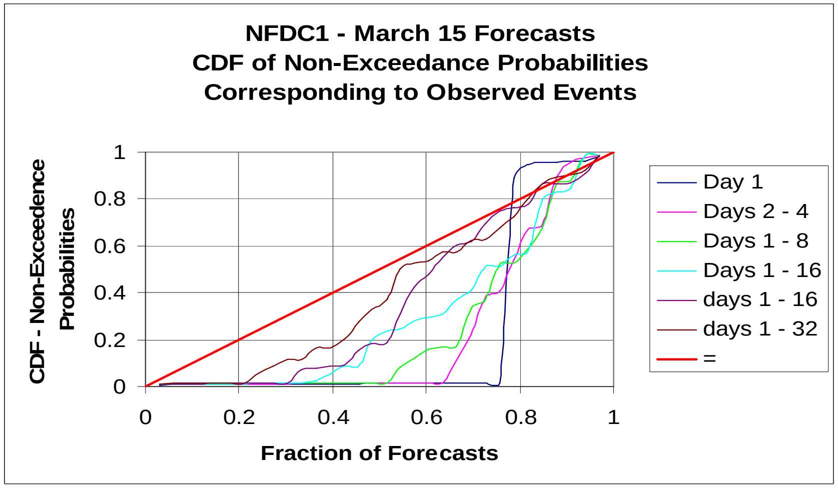


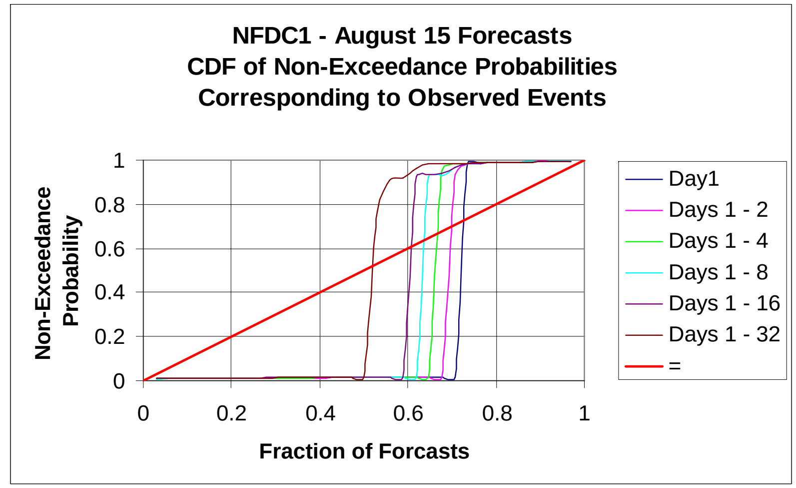
Need for Hydrologic Ensemble Post-Processing

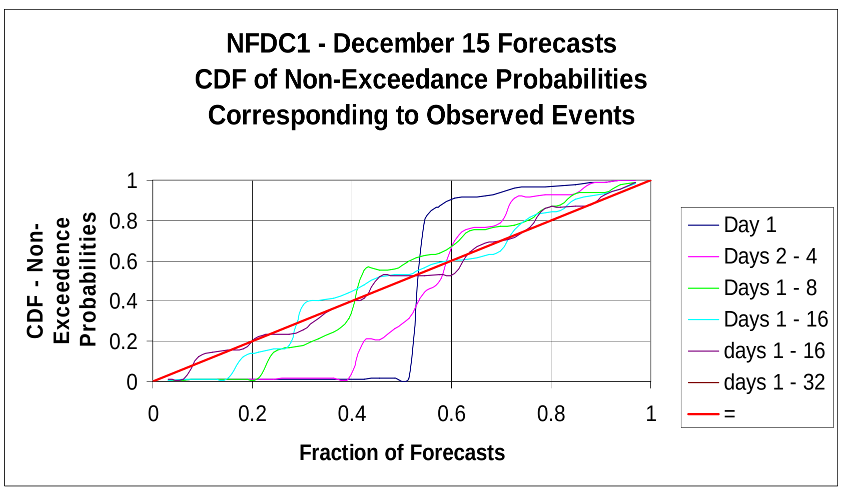
- **ESP forecasts are conditioned on an ensemble of precipitation and temperature forecasts (i.e. ysim|fcst).**
  - If the input P &T ensemble members are "properly calibrated" they will have the same long-term climatology as the historical P & T used for hydrologic model calibration.
  - Climatological ESP runs using the historical data are, by construction, use P & T that are "properly calibrated".
  - This means that problems with the hydrologic ensemble forecasts are due to "hydrologic model bias and uncertainty" if input forcing is "properly calibrated".

- **Hydrologic model bias and uncertainty occur because:**
  - Hydrologic model simulations cannot produce hydrologic products that are always completely unbiased.
  - Current ESP forecasts assume that the initial conditions are known. This causes the ESP spread to be underestimated, especially for forecast periods with little P & T forcing variability.
  - Hydrologic model simulations do not account for hydrologic model error (structure and parameters). This also causes the ESP spread to be underestimated.

Spread Bias in Climatological ESP: Cumulative Rank Histograms for NFDC1

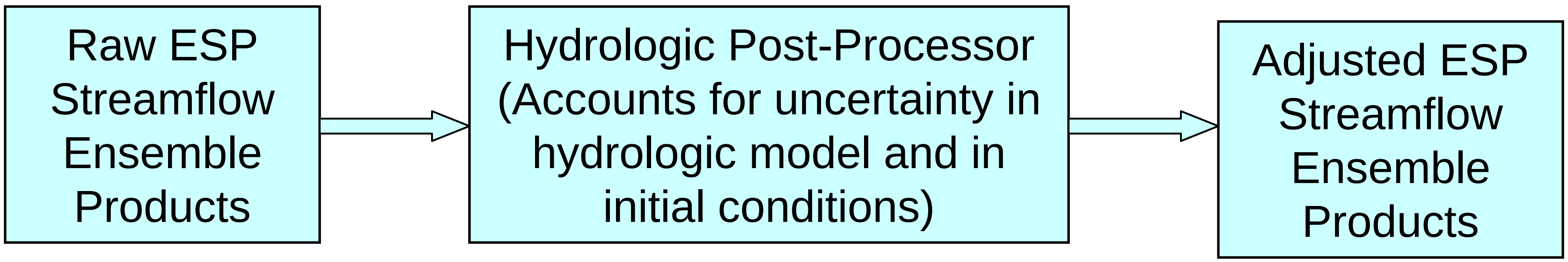






Note:
These ESP runs were made with an "old" calibration for NFDC1.
The new calibration is almost unbiased for March 15 forecasts.

Hydrologic Ensemble Product Post-Processor (to correct raw ESP bias and spread errors)



This post-processor operates on hydrologic “products” only. These products are derived for a “window” superimposed on an ensemble of ESP hydrographs. Within this window, the “product” is defined in terms of an “operation” on each hydrograph within the window. Example operations include: average, maximum, minimum, minimum of x-day average, volume in window, etc.

This post-processor DOES NOT adjust the raw ensemble time series members. It DOES produce adjusted values for the individual product members that:

1. Preserves the “skill” of the raw ensemble forecast
2. Removes mean bias
3. Produces reliable probability forecasts

Hydrologic Post-Processor

- The ESP program generates an ensemble of streamflow forecasts that are conditioned on an ensemble of precipitation and temperature forecasts (i.e. ysim|fcst)
- These ESP forecasts assume that the initial conditions are known and that the hydrologic model is perfect
- The relationship between historical observations and simulations can be used to represent the uncertainty associated with the fact that the initial conditions are not known exactly and the model is imperfect (i.e. yobs|ysim)
- If we neglect the uncertainty in the relationship between yobs and ysim that is caused by the uncertainty in the estimated forcing used to generate ysim during the forecast period, the pdf of yobs, given the ensemble of precipitation and temperature forecasts can be estimated by the relationship:

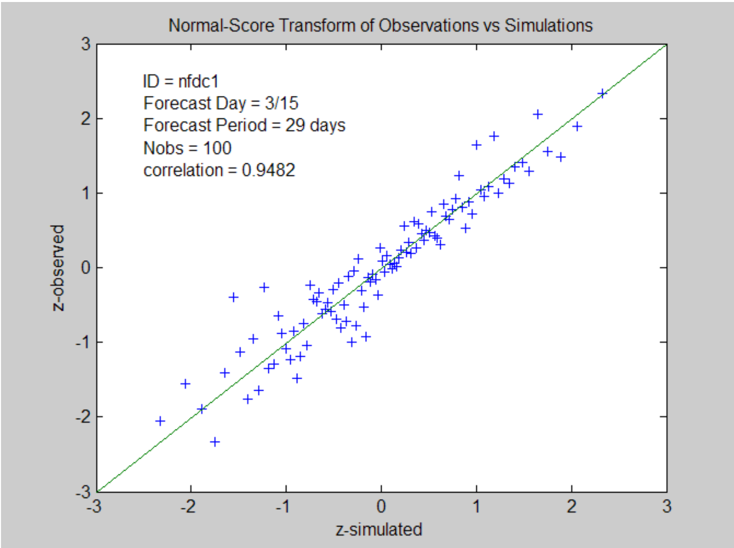
$$f\left(yobs \mid fcst\right) = \int_0^{+\infty} f\left(yobs \mid ysim\right) f\left(ysim \mid fcst\right) dysim$$

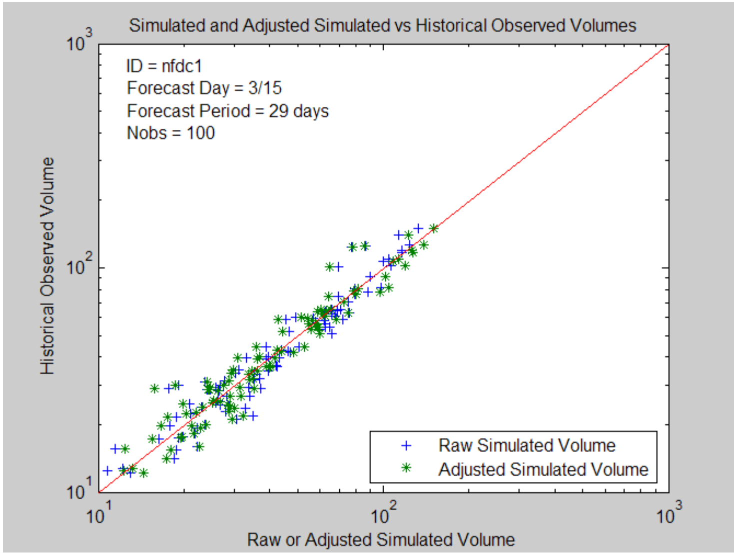
Adjusted ESP Forecast

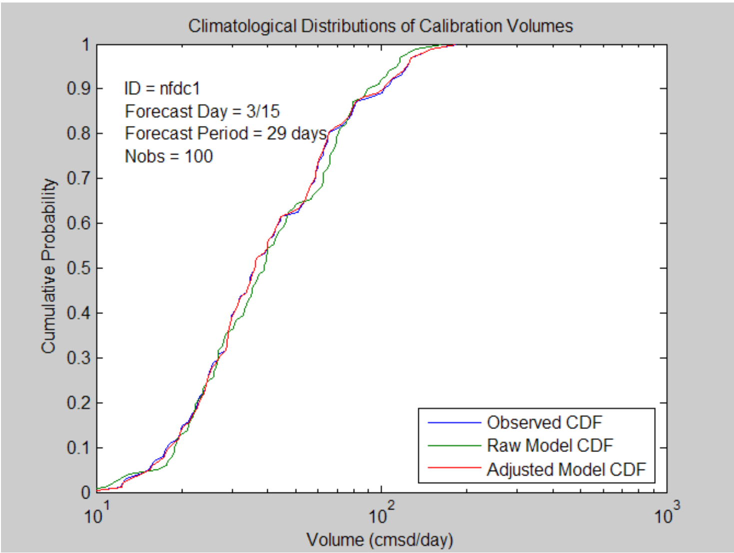
Historical Simulation

Raw ESP Forecast

NFDC1 – March 15
30-day Post-Processor Calibration

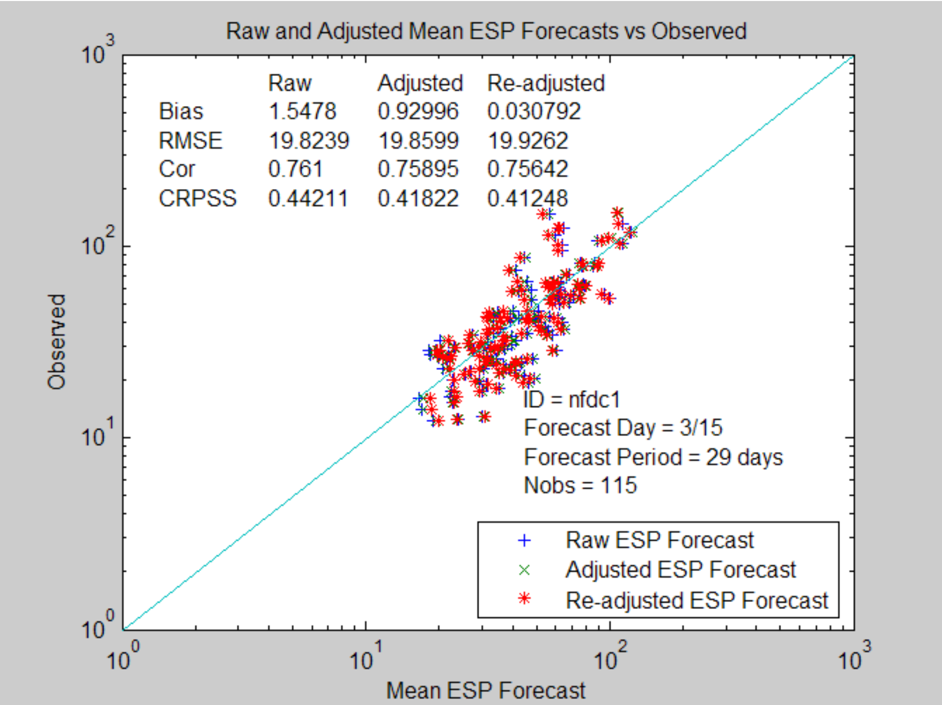




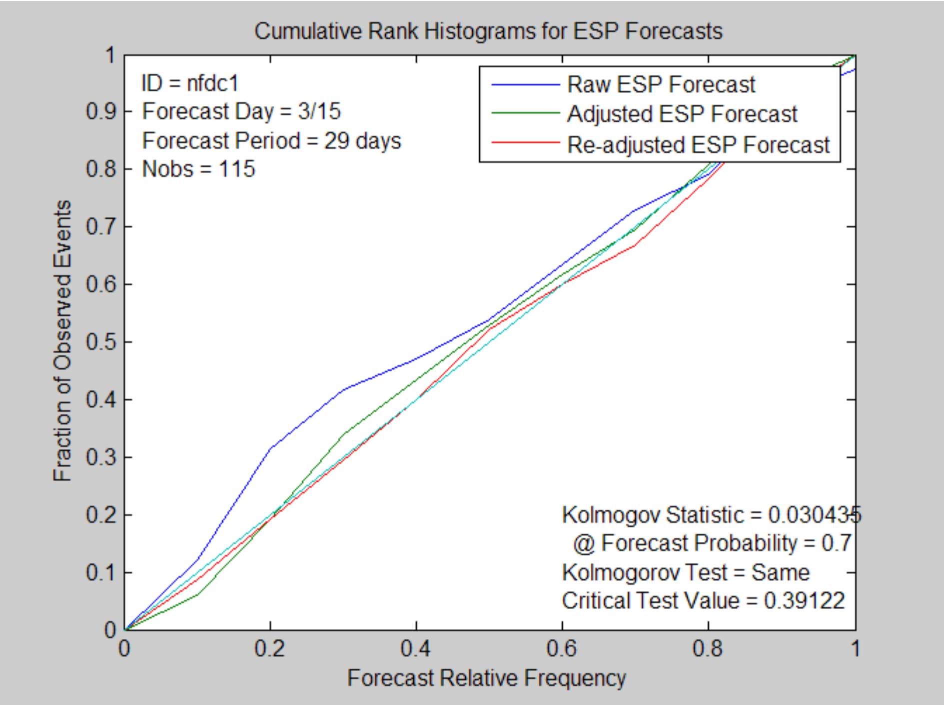


Analysis of Historical Model Simulation Results (new NFDC1 calibration)

NFDC1 – March 15
30-day GFS-Based
Hydrologic Ensemble Forecasts

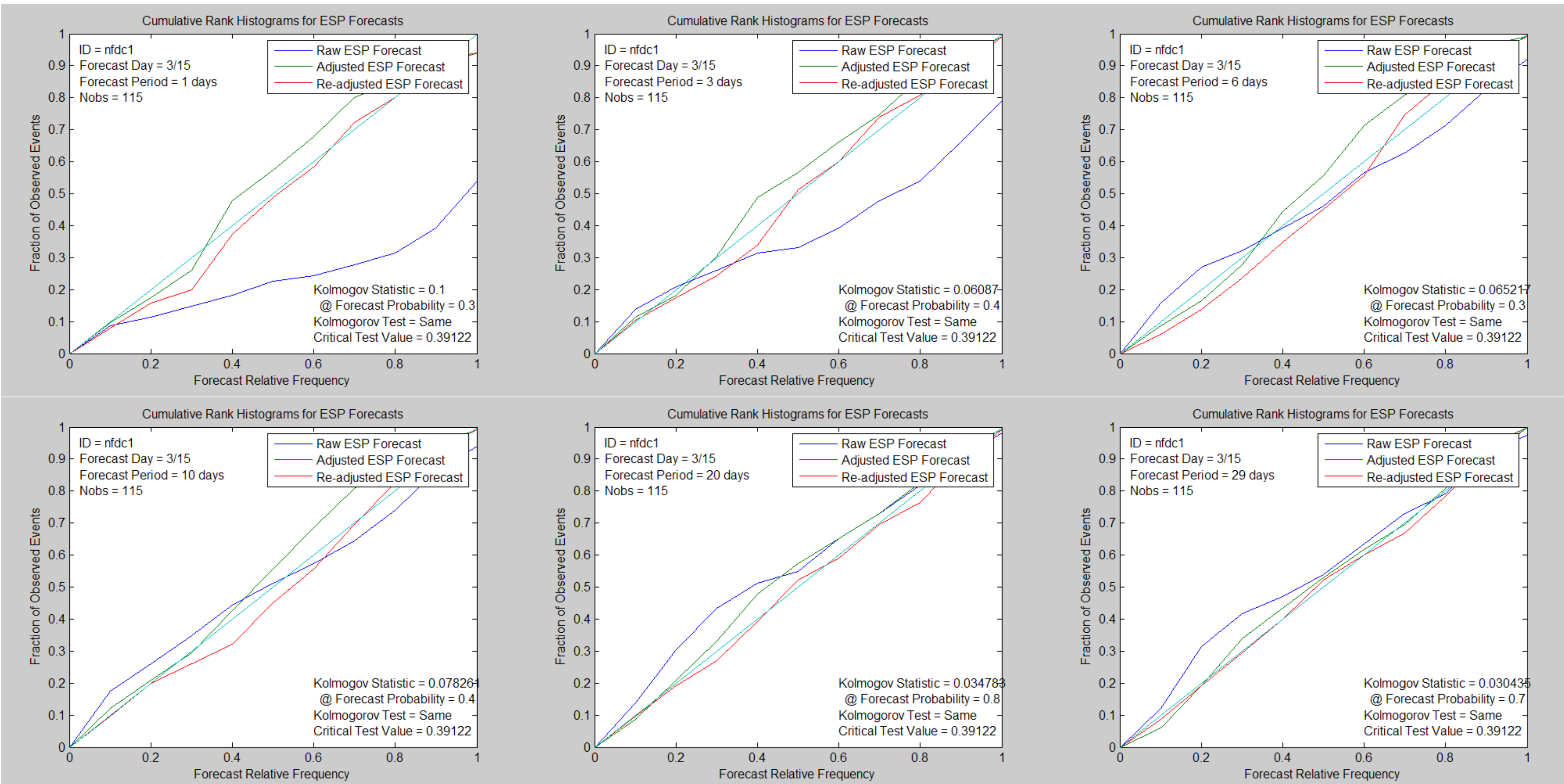


Ensemble Mean vs Observed

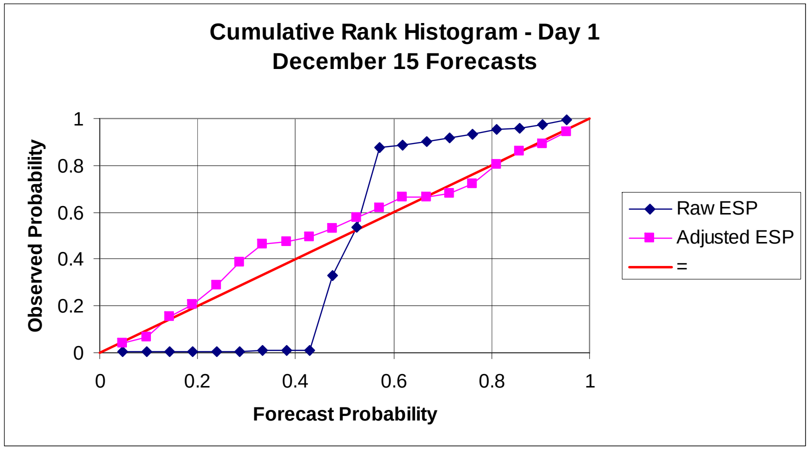


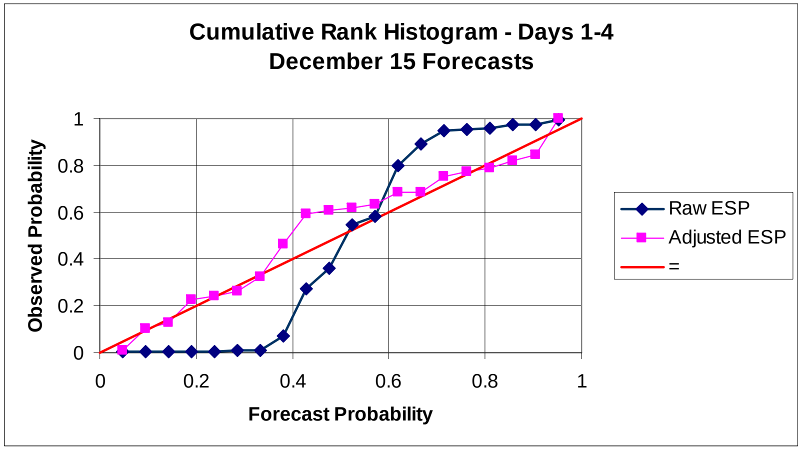
Cumulative Rank Histograms

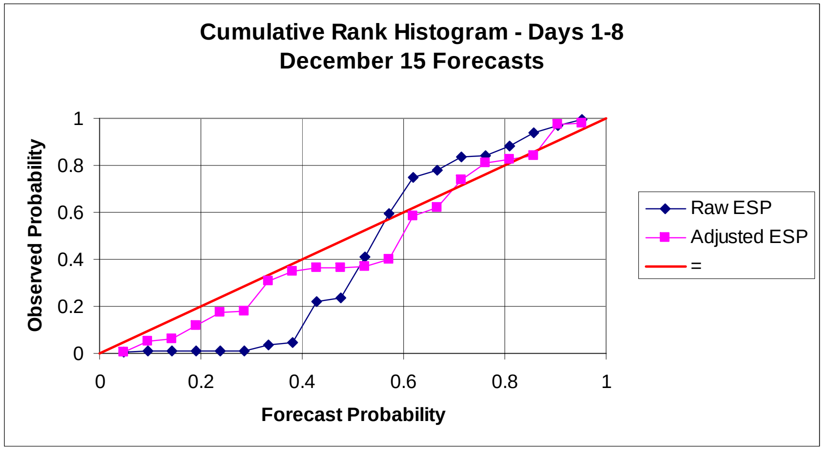
NFDC1 – March 15 Forecasts Cumulative Rank Histograms for Different Forecast Products

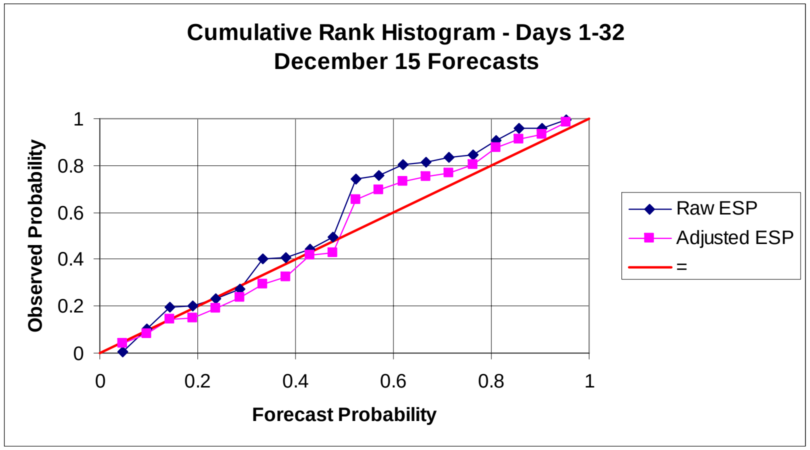


Cumulative Rank Histograms (NFDC1) December 15 Forecasts





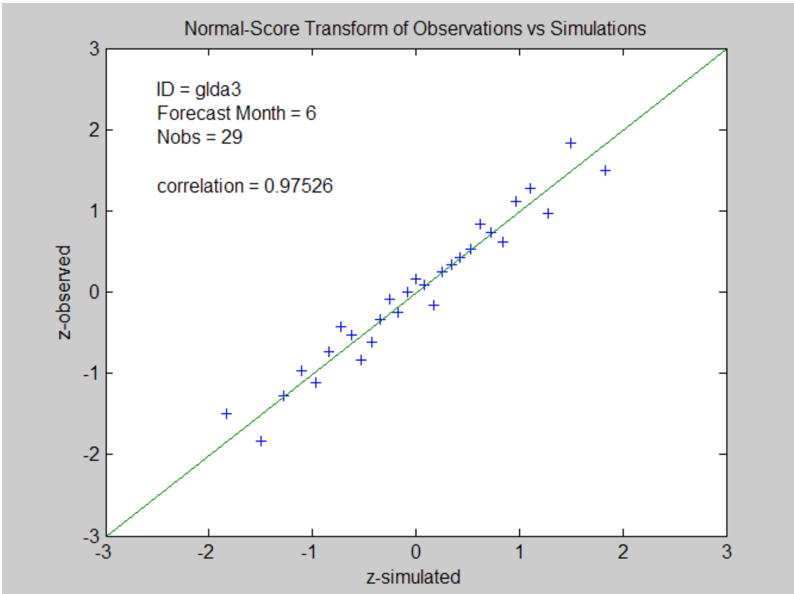


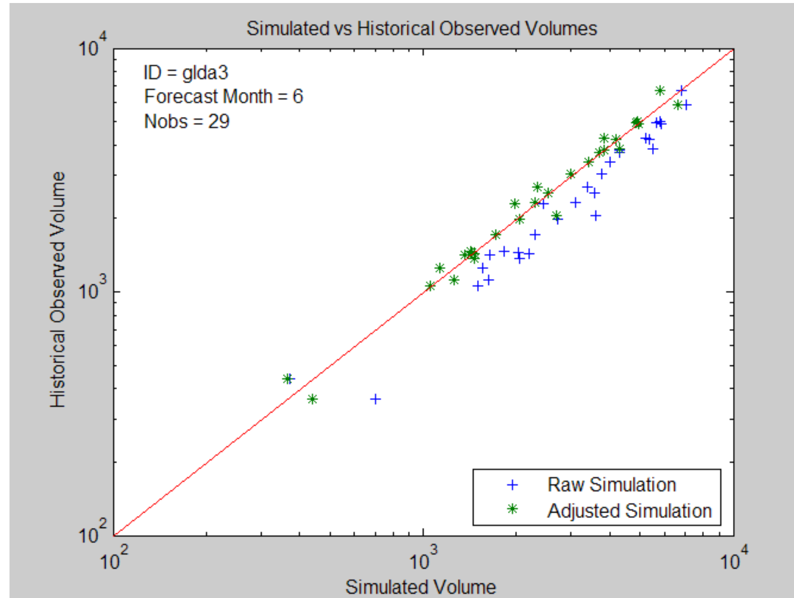


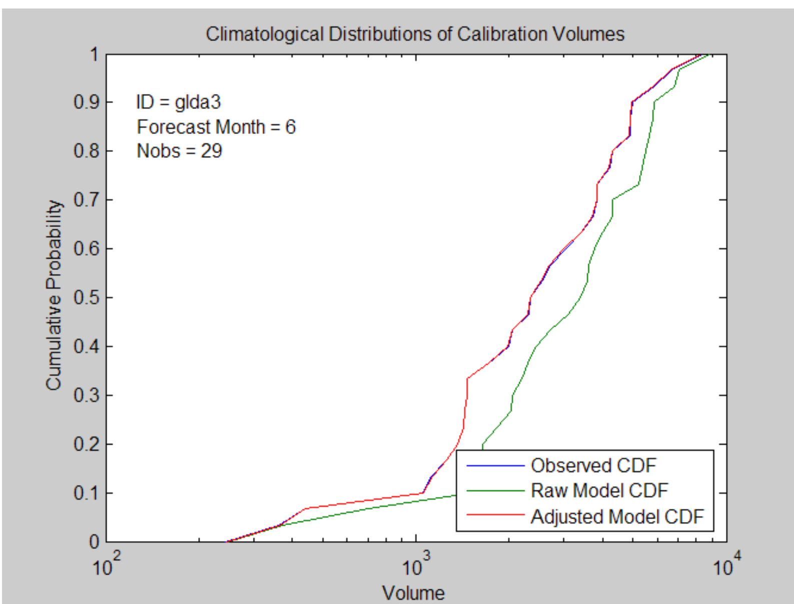
GLDA3
(Lake Powell Inflow)

EPG Post-Processor Calibration Results

June Calibration – Lake Powell

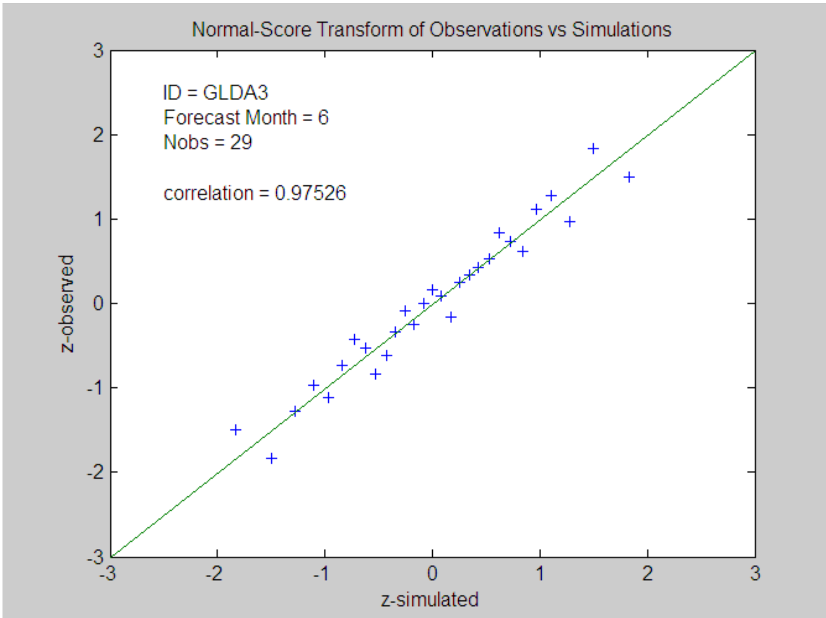


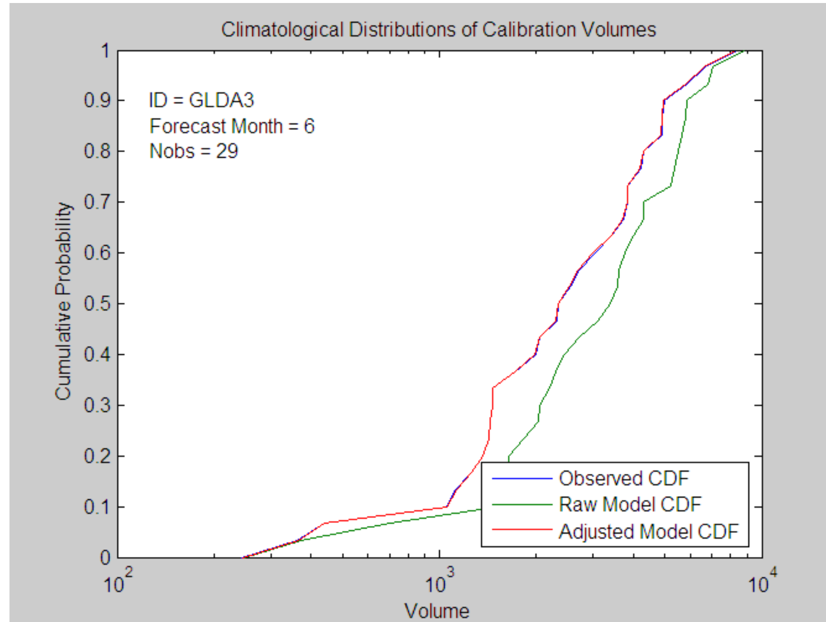


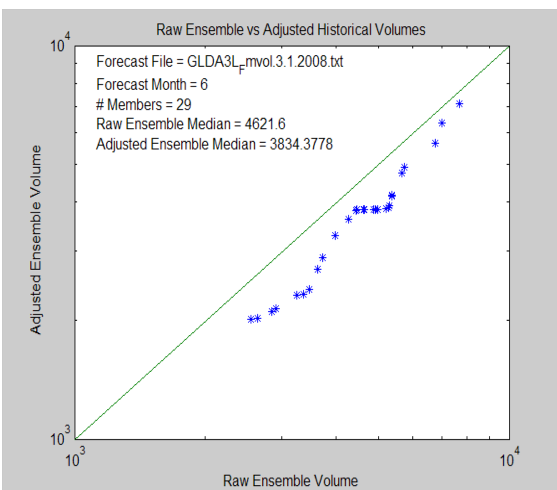


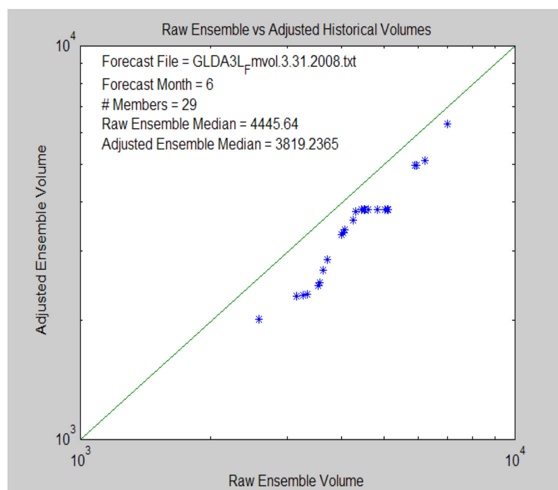
Analysis of joint relationship between Historical Model Simulation Results and Historical USBR values of Lake Powell Inflow

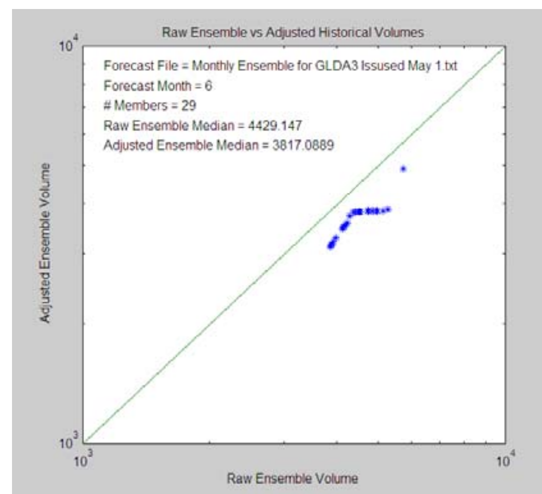
Recent June Forecasts



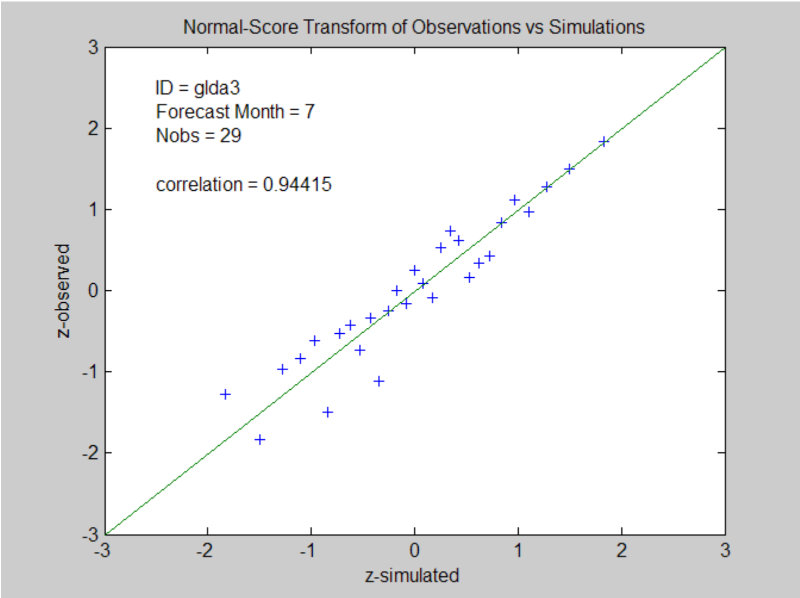


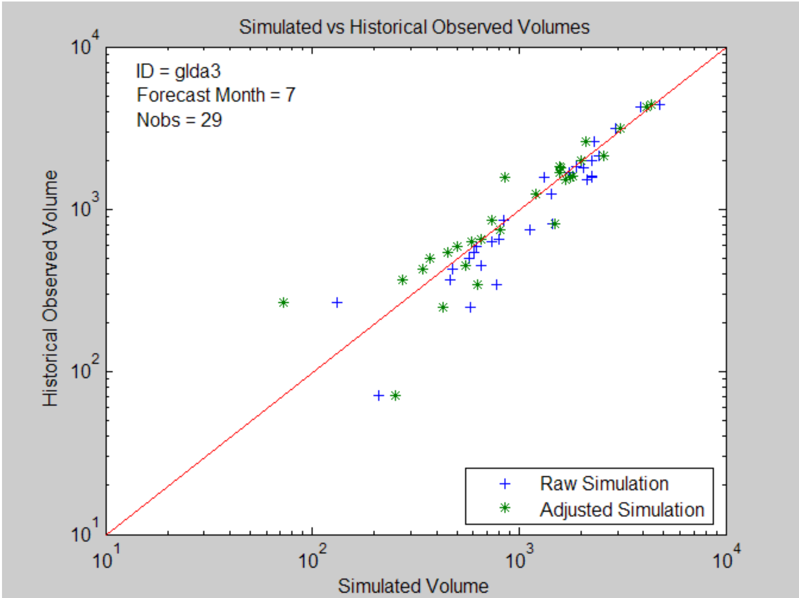


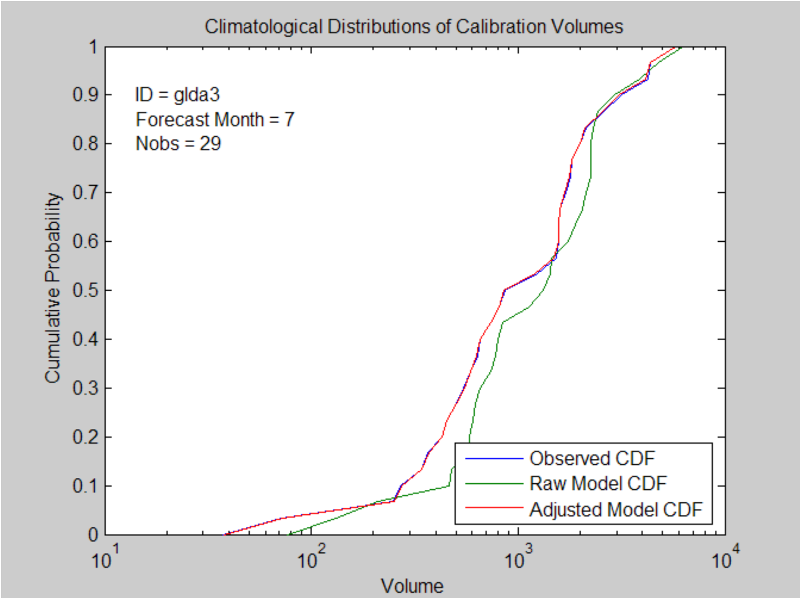




July Calibration – Lake Powell

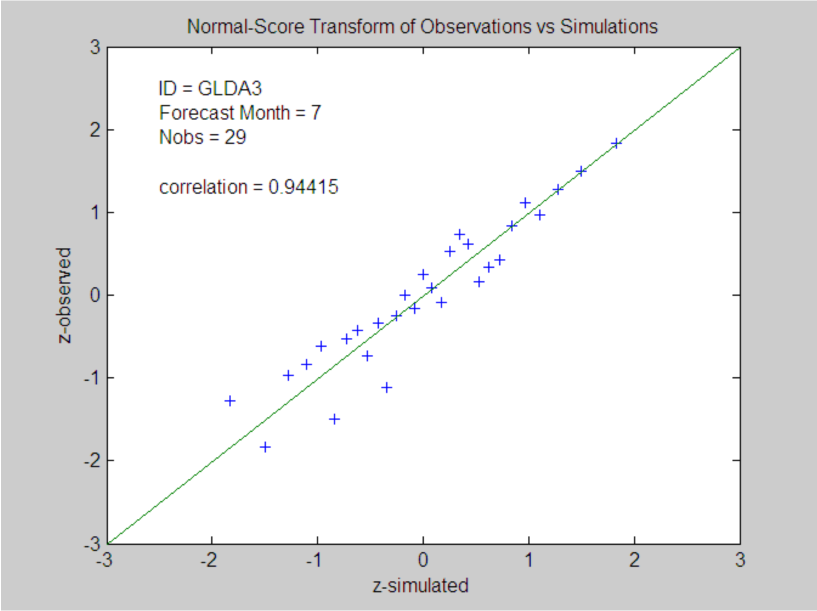


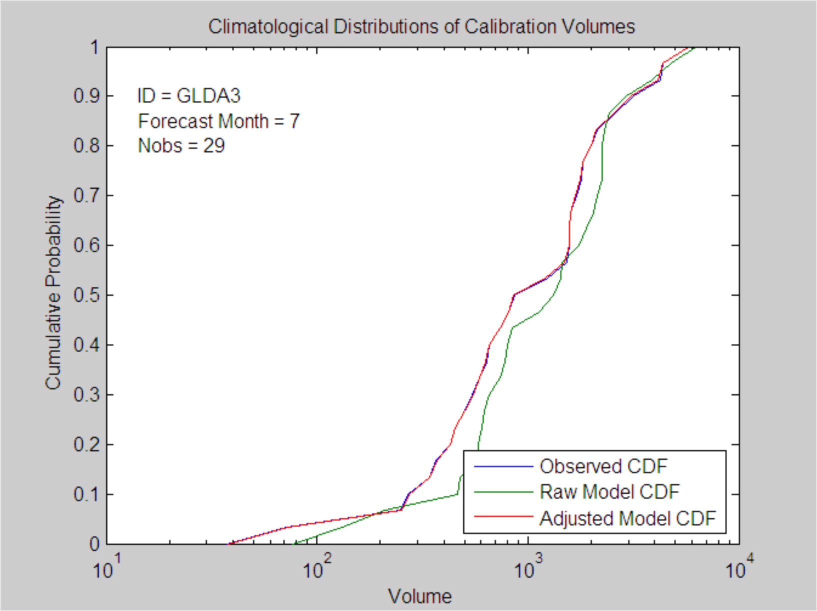


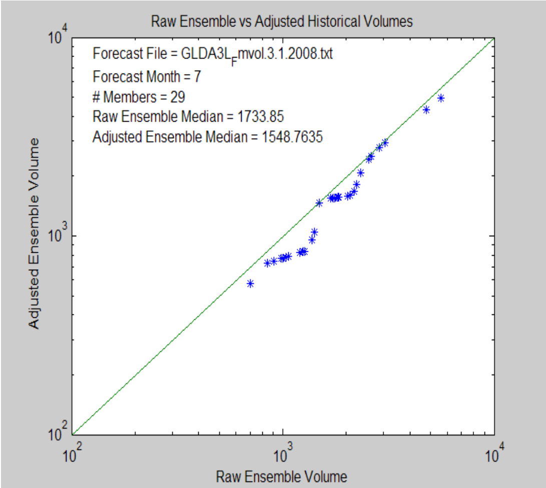


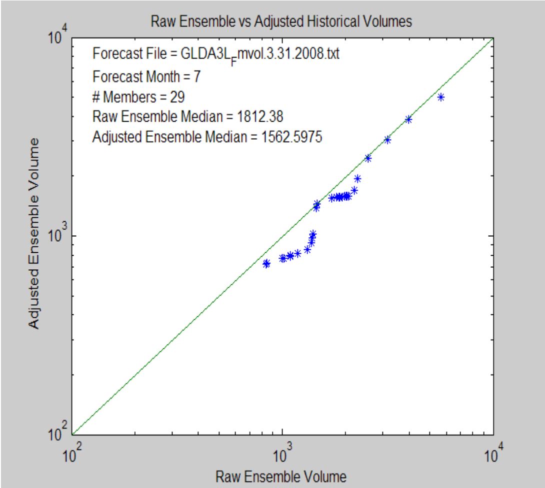
Analysis of joint relationship between Historical Model Simulation Results and Historical USBR values of Lake Powell Inflow

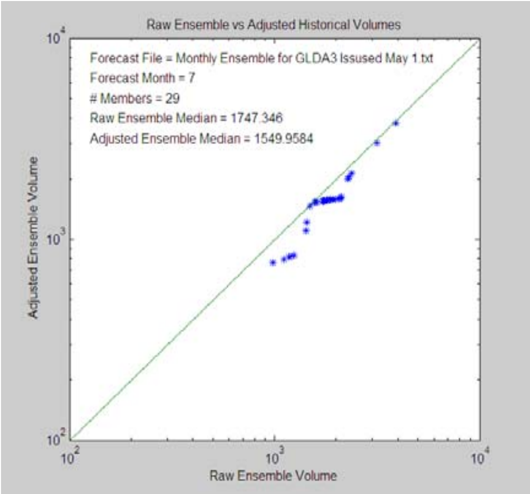
Recent July Forecasts









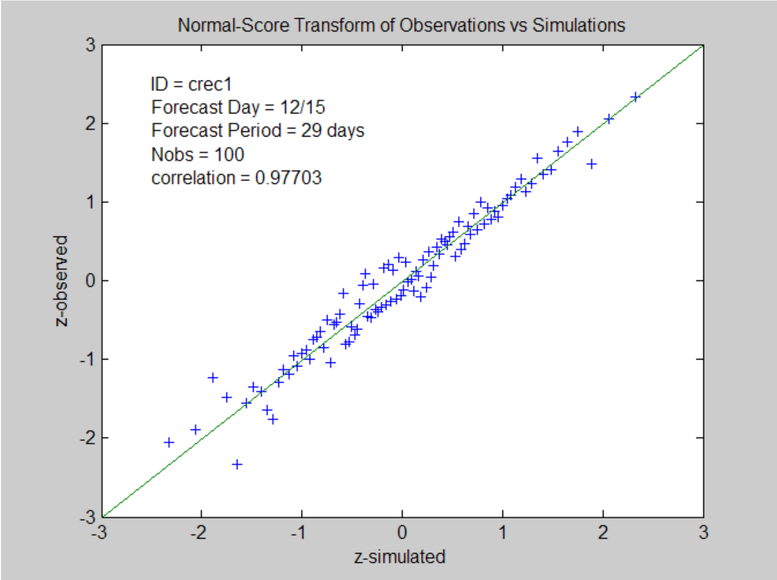


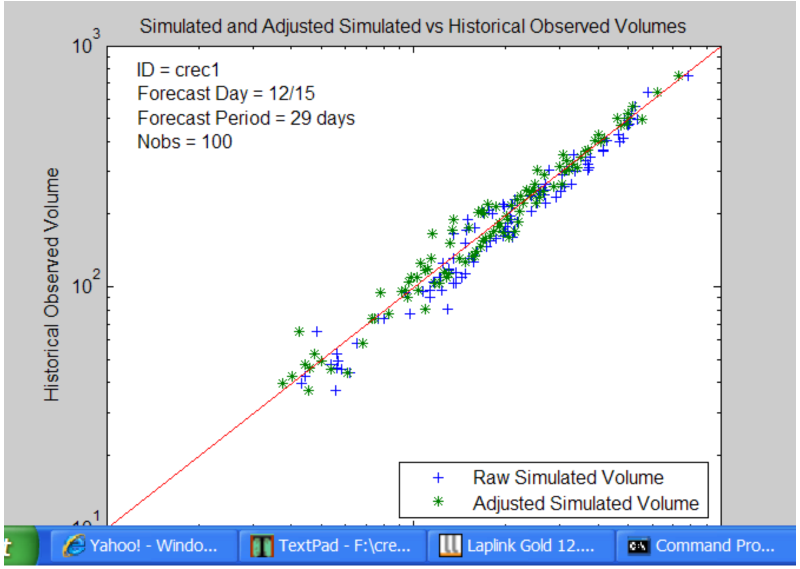
LAMC1
(Lake Mendocino, CA)

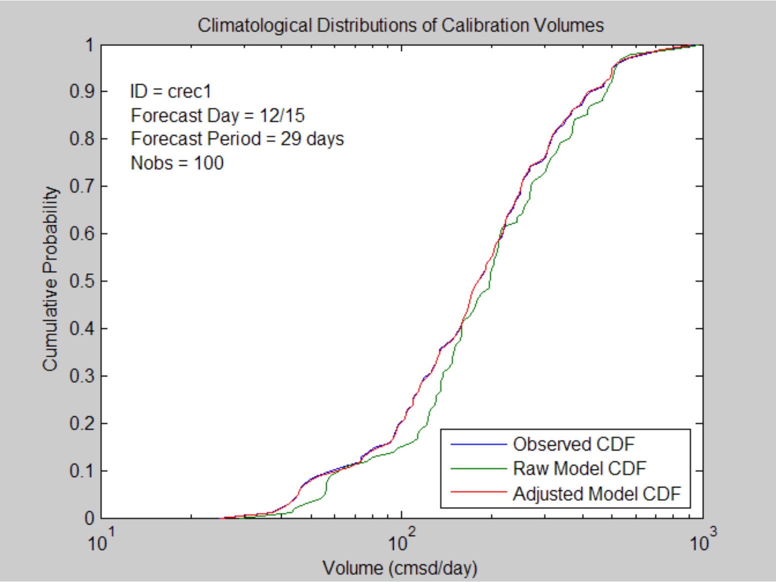
Russian River Basin

CREC1 – R0G14C30

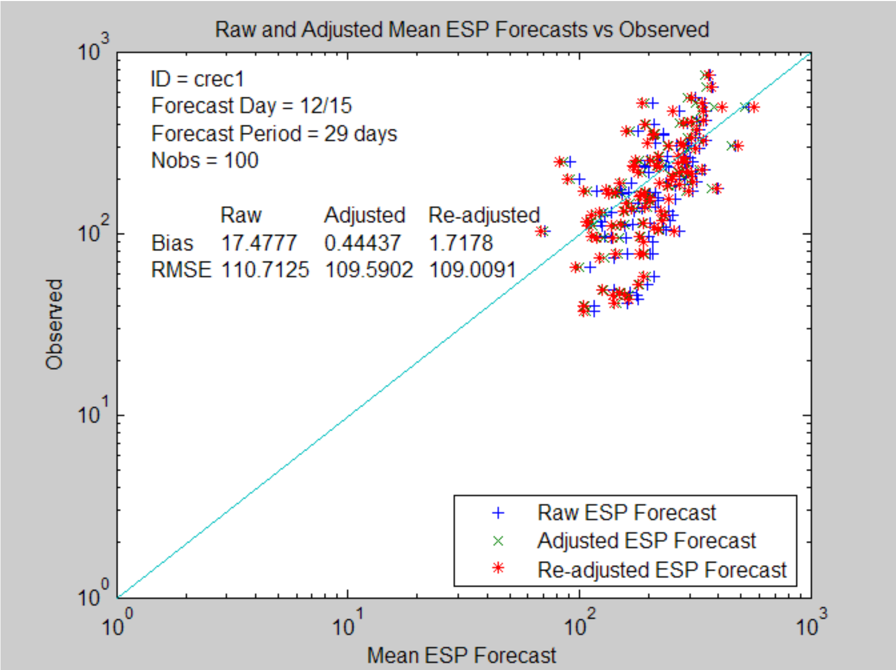
December 15: 29-day Calibration

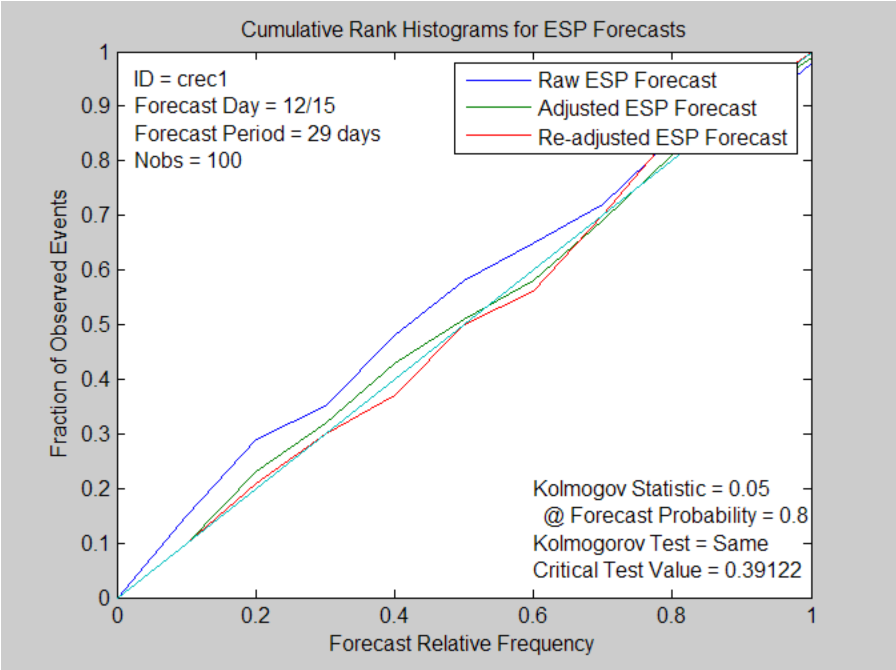




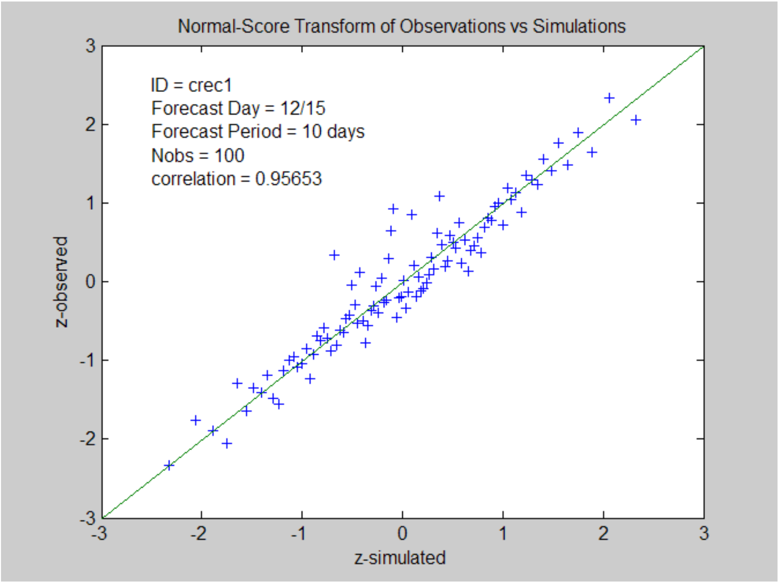


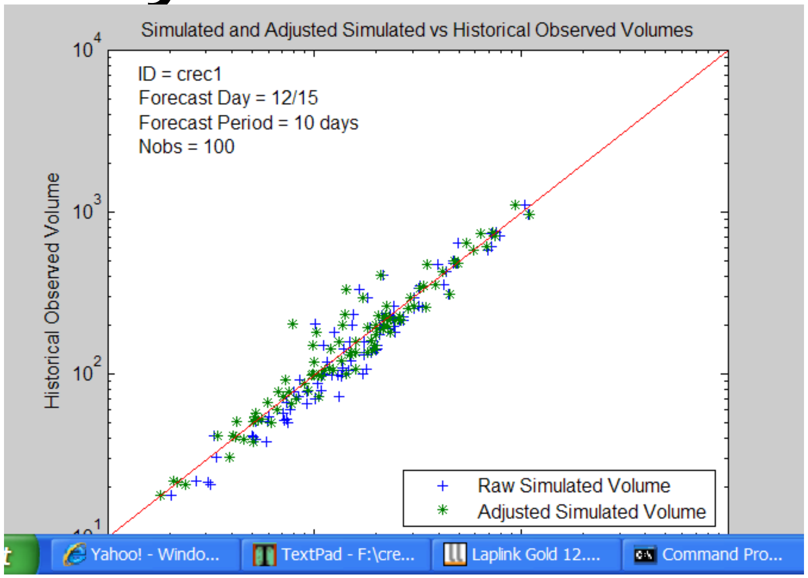
December 15: 29-day Forecasts

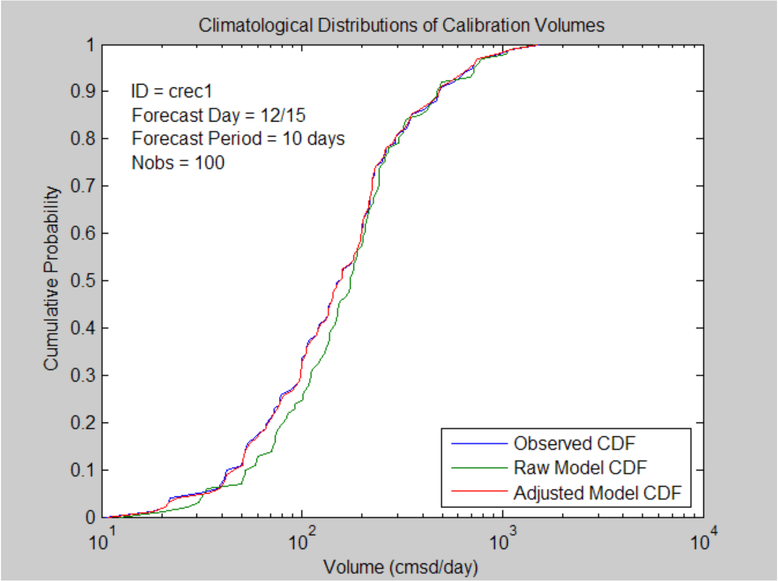




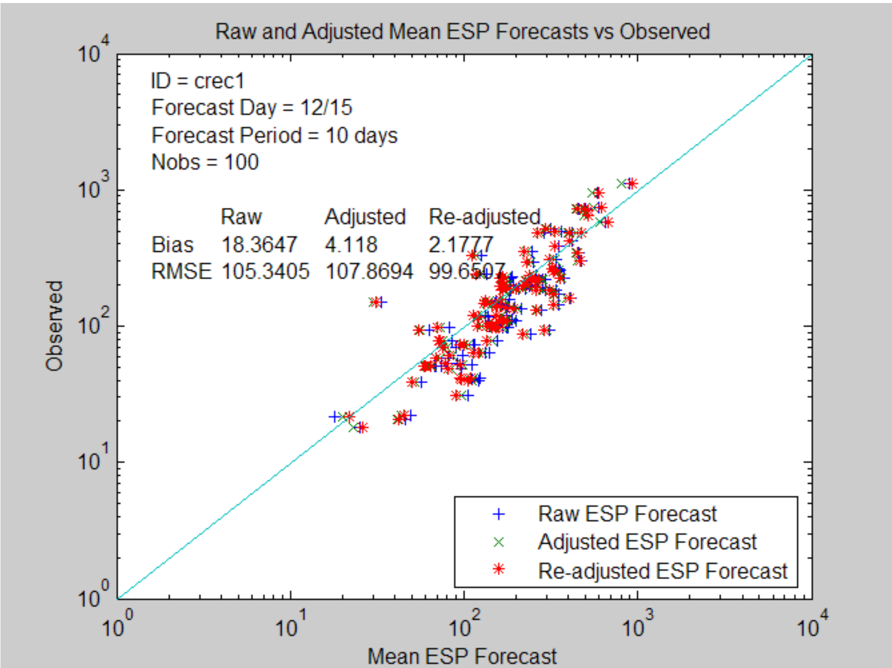
December 15: 10-day Calibration

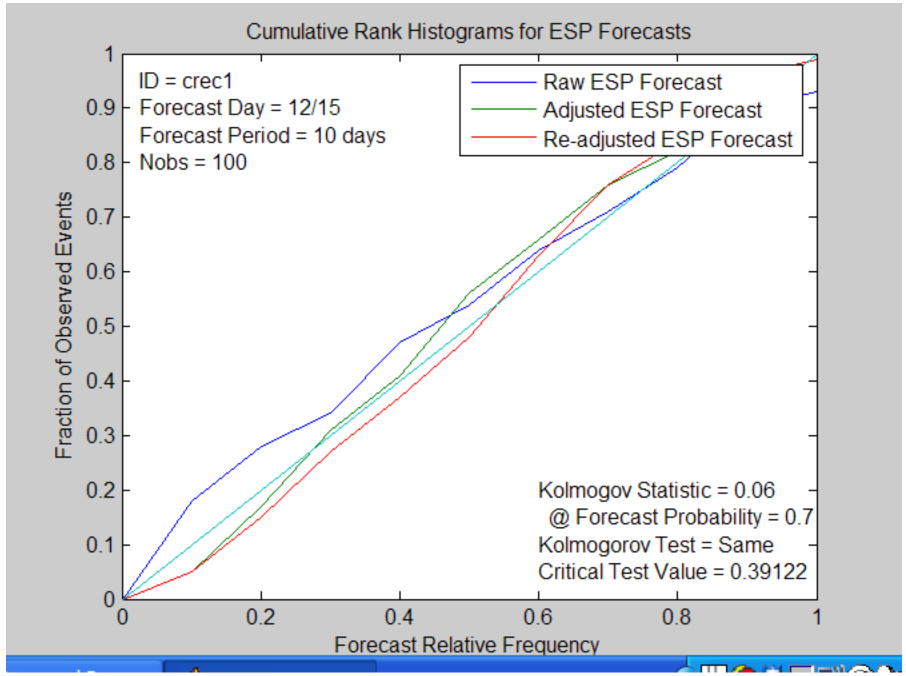




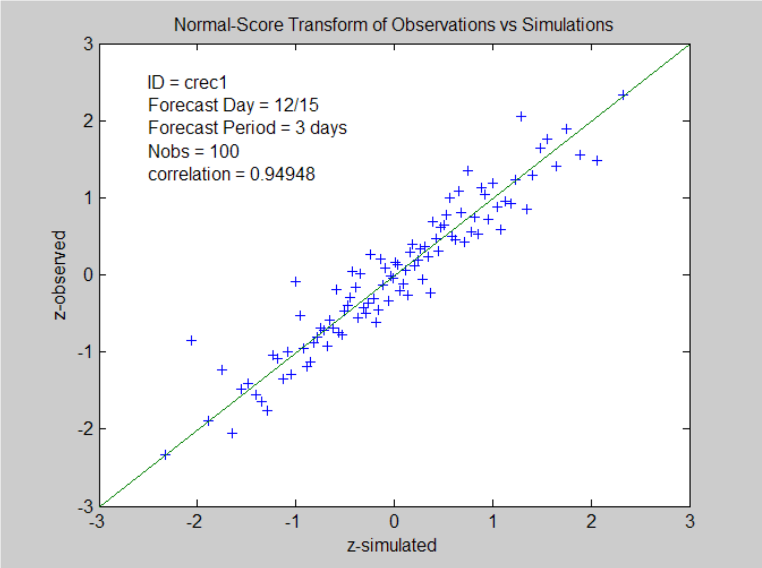


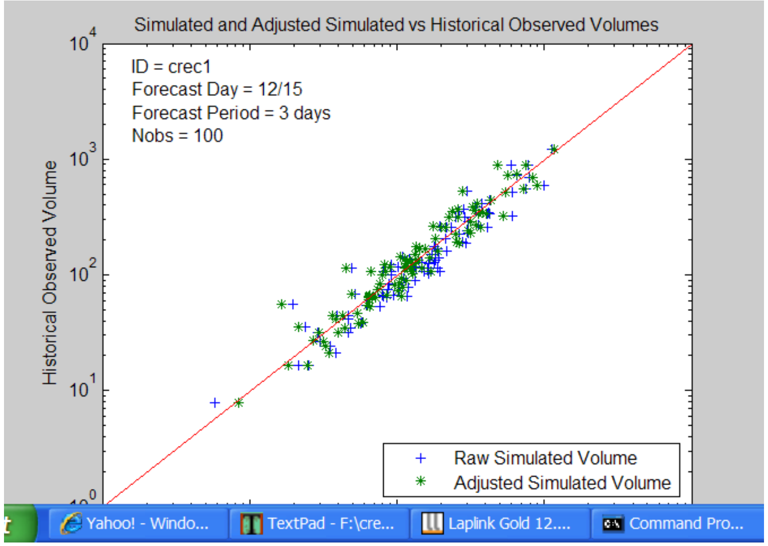
December 15: 10-day Forecasts

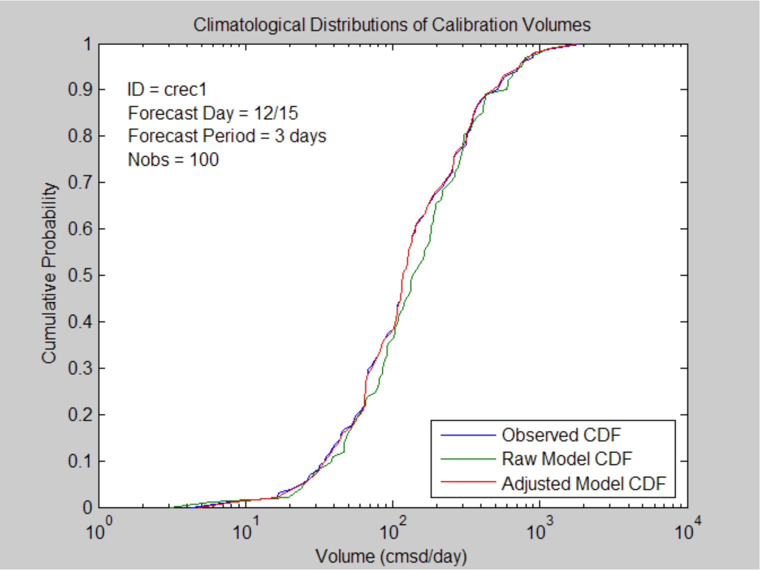




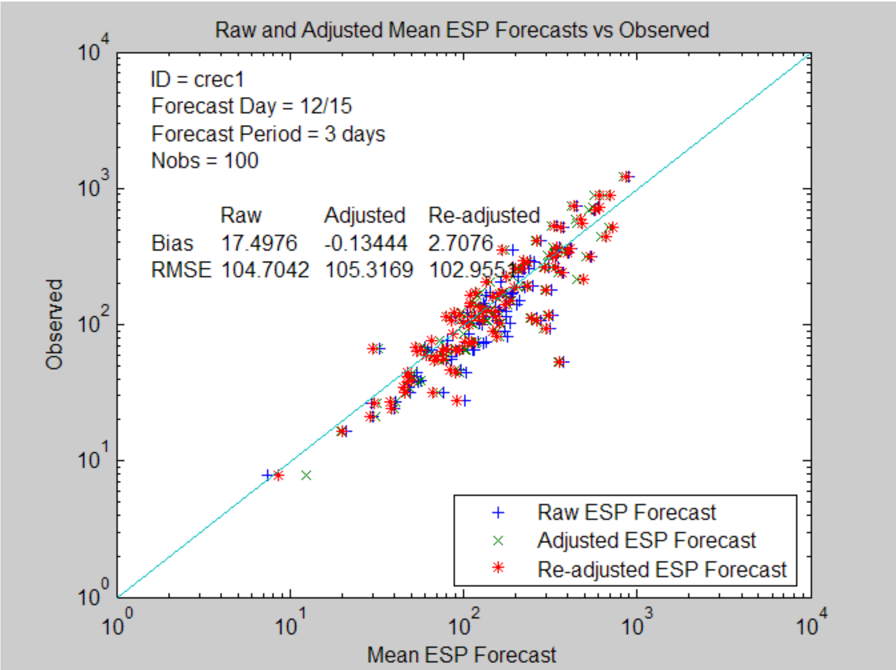
December 15: 3-day Calibration

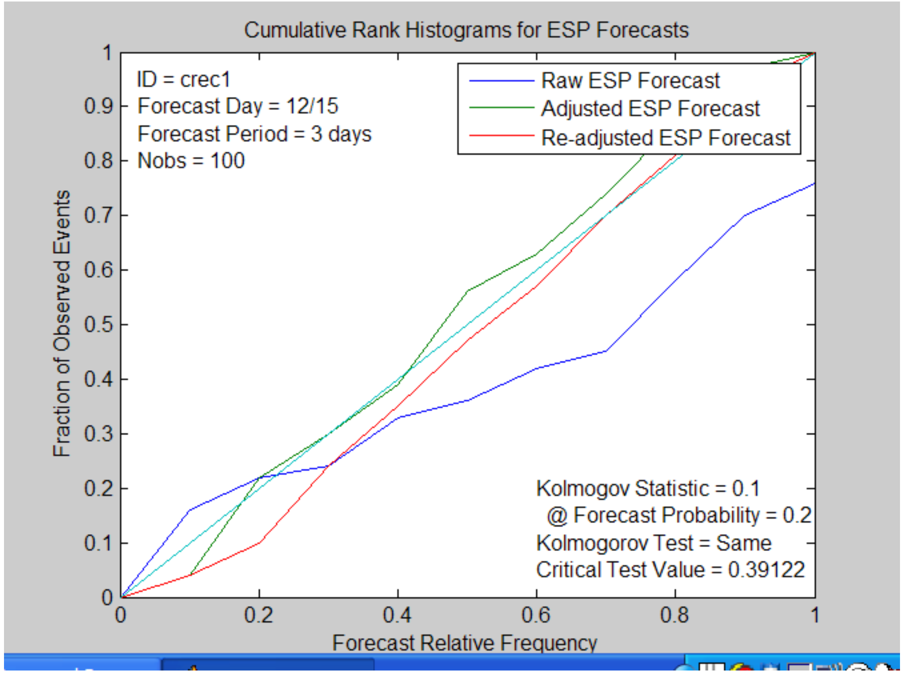






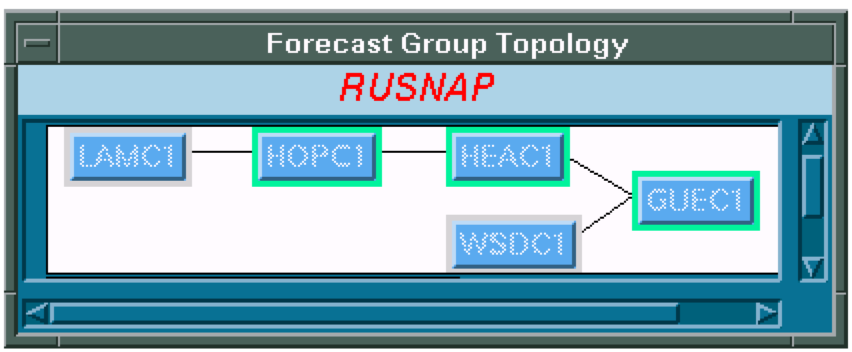
December 15: 3-day Forecasts

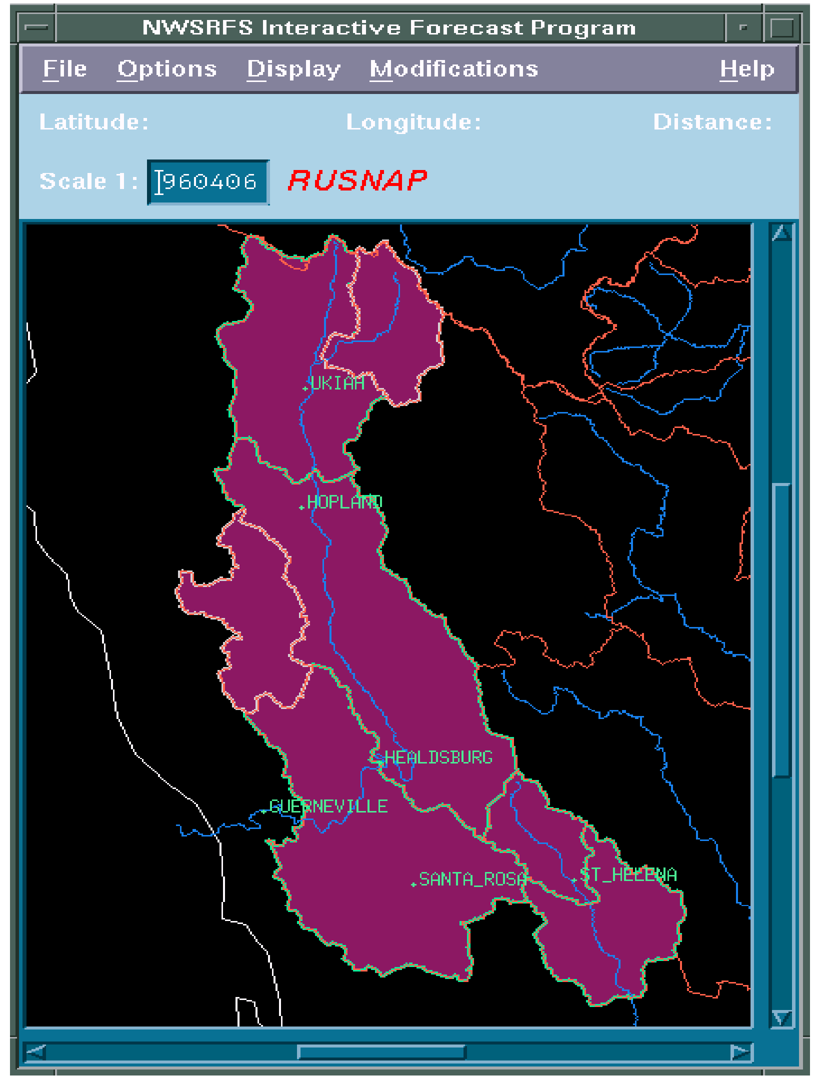




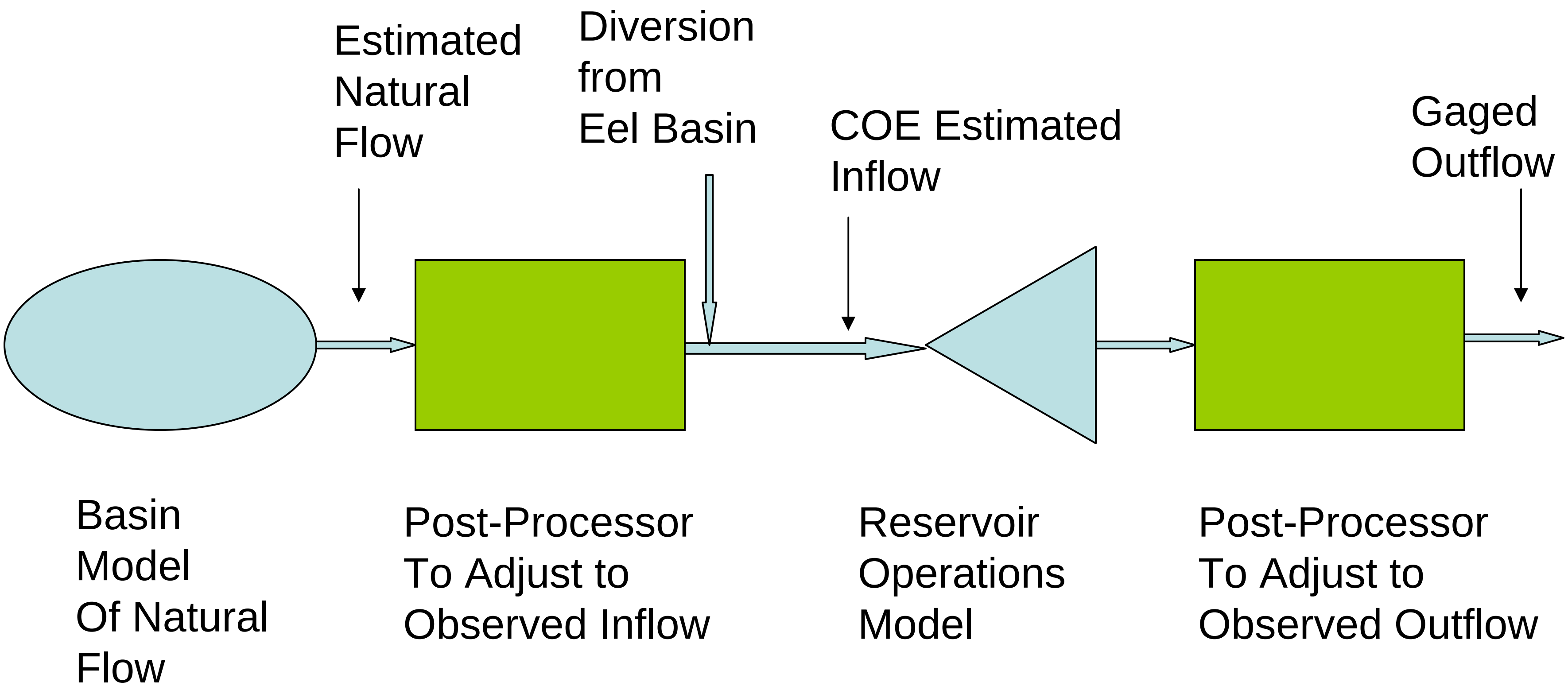
Russian River

- Total Area 3465 km2.
- Elevation 17m - 1245m.
- 2 Flood Control Reservoirs
- Upstream Diversions
- 3 Local Areas.
- 3 Official Flood Forecast Points.
- Floods Nearly Every Year.
- 3 Major Floods in Past 40 Years.



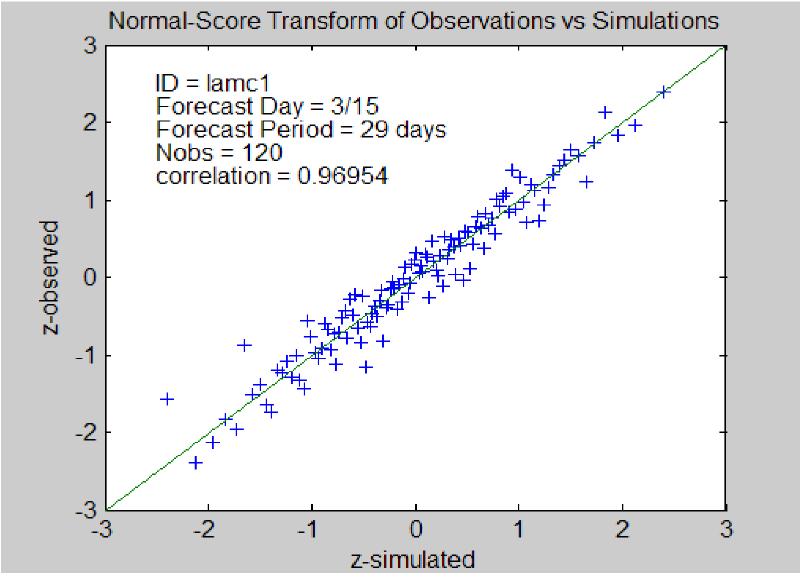


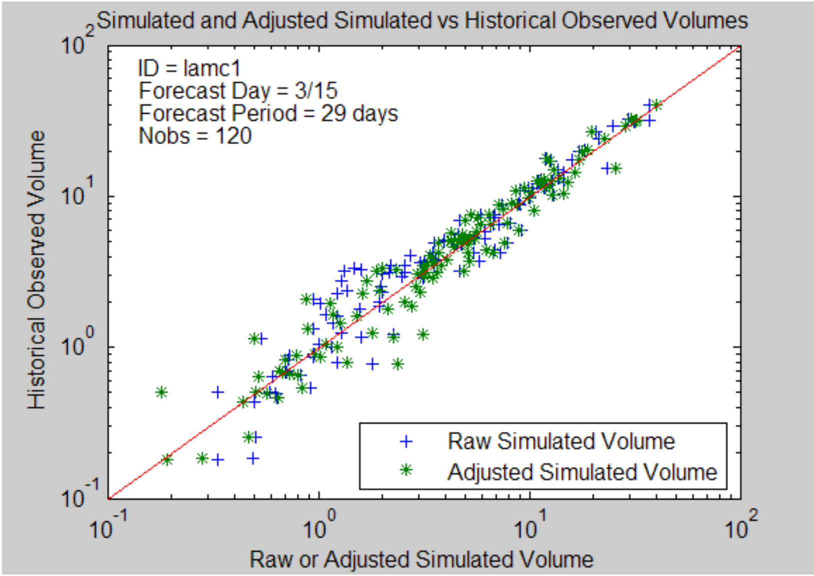
LAMC1 – Schematic of Possible Post Processor Applications

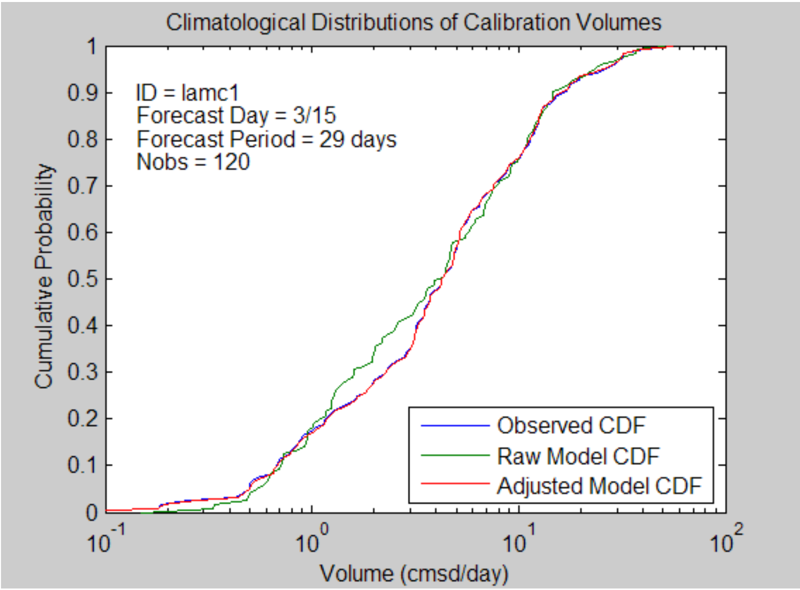


Note: To produce the "best" ESP products it will be necessary to route adjusted ensemble time series members downstream and then apply Post Processor techniques to downstream points after upstream adjustments have been made. (XEFS Requirement).

Full Natural Flow – March 15

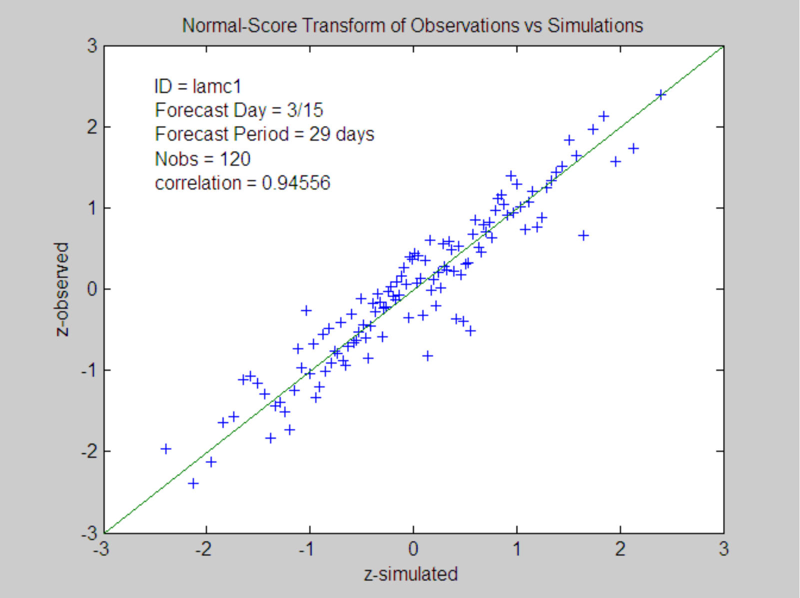


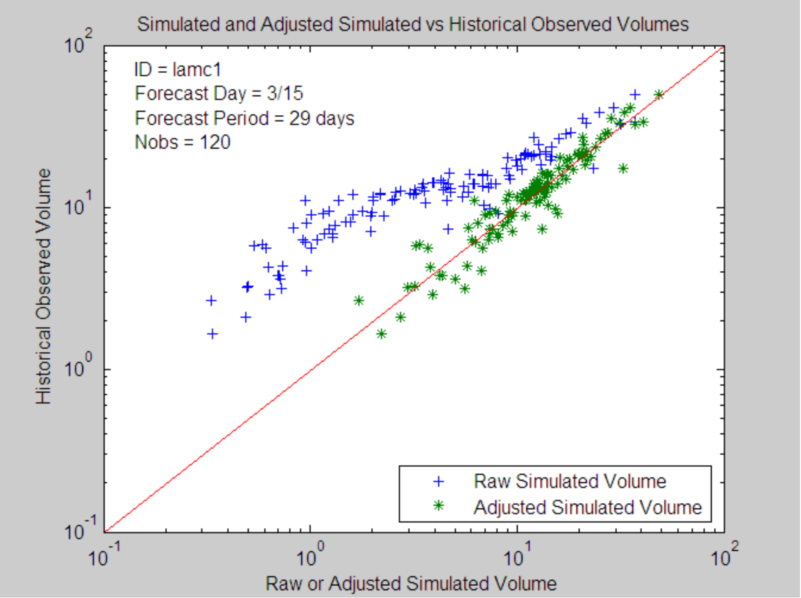


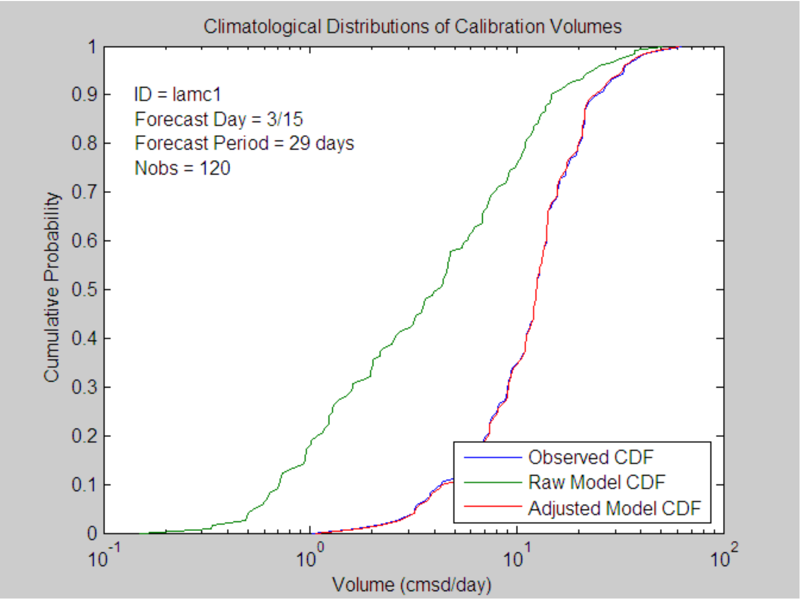


Analysis of Historical Model Simulation Results of Full Natural Flow

Full Natural Flow to Inflow – March 15

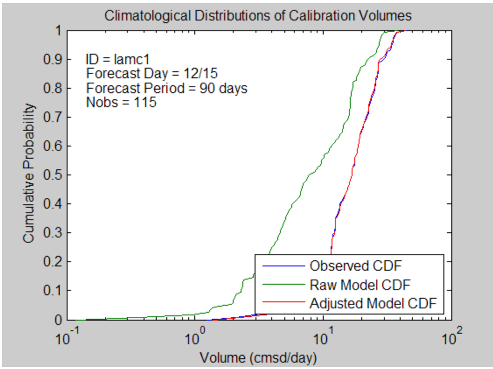


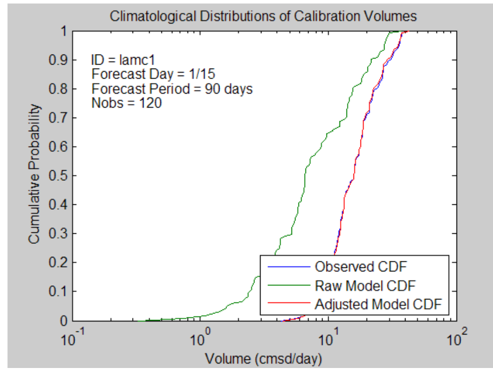


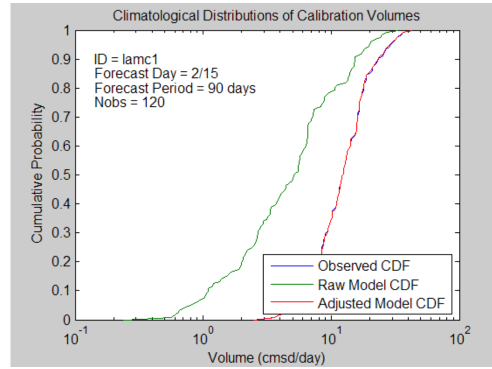


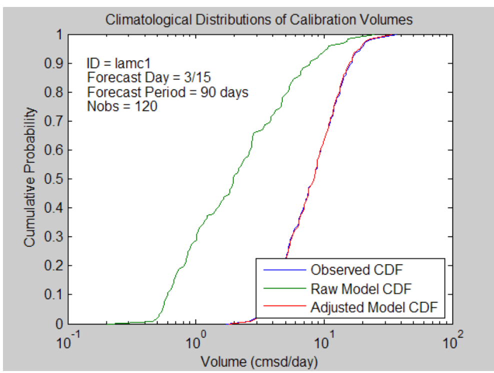
Analysis of Historical Model Simulation Results of Full Natural Flow and Reservoir Inflow (that includes upstream diversion from the Eel river basin)

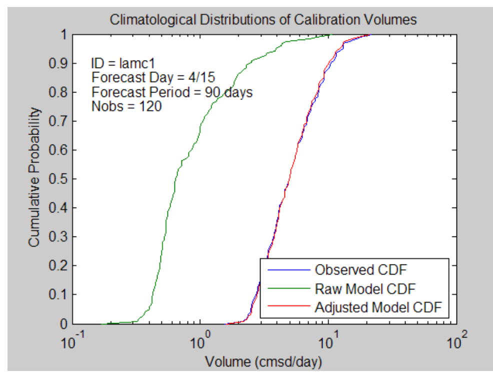
Climatologies of Measured Inflow and Modeled Natural Flow (December – June)

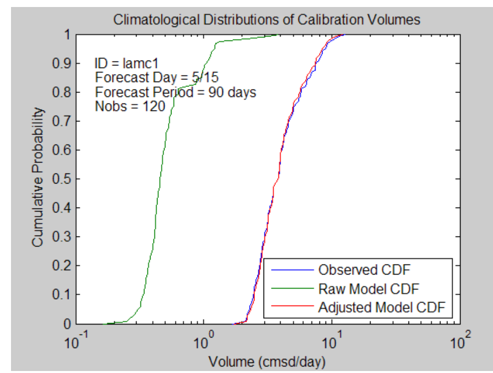


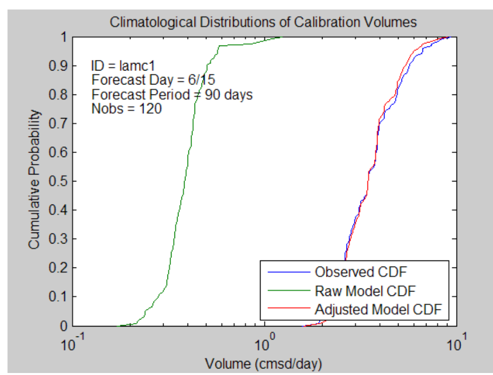




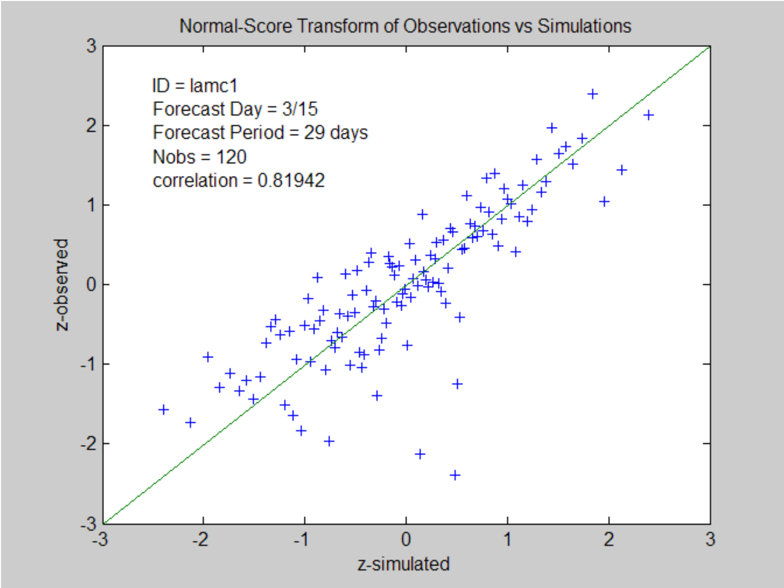


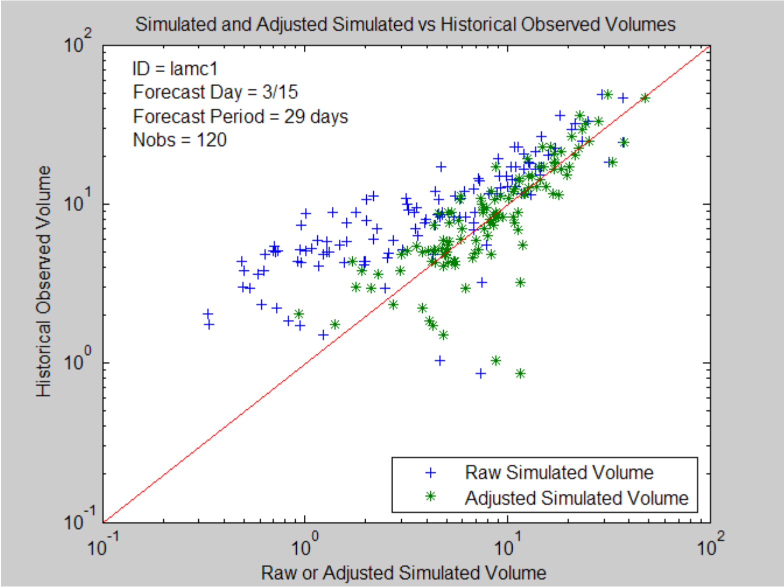


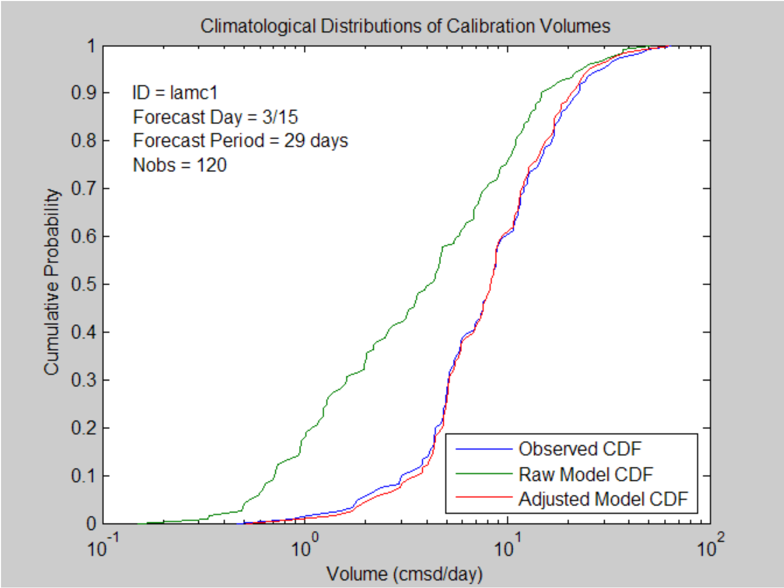




Full Natural Inflow to Resevoir Outflow - March 15







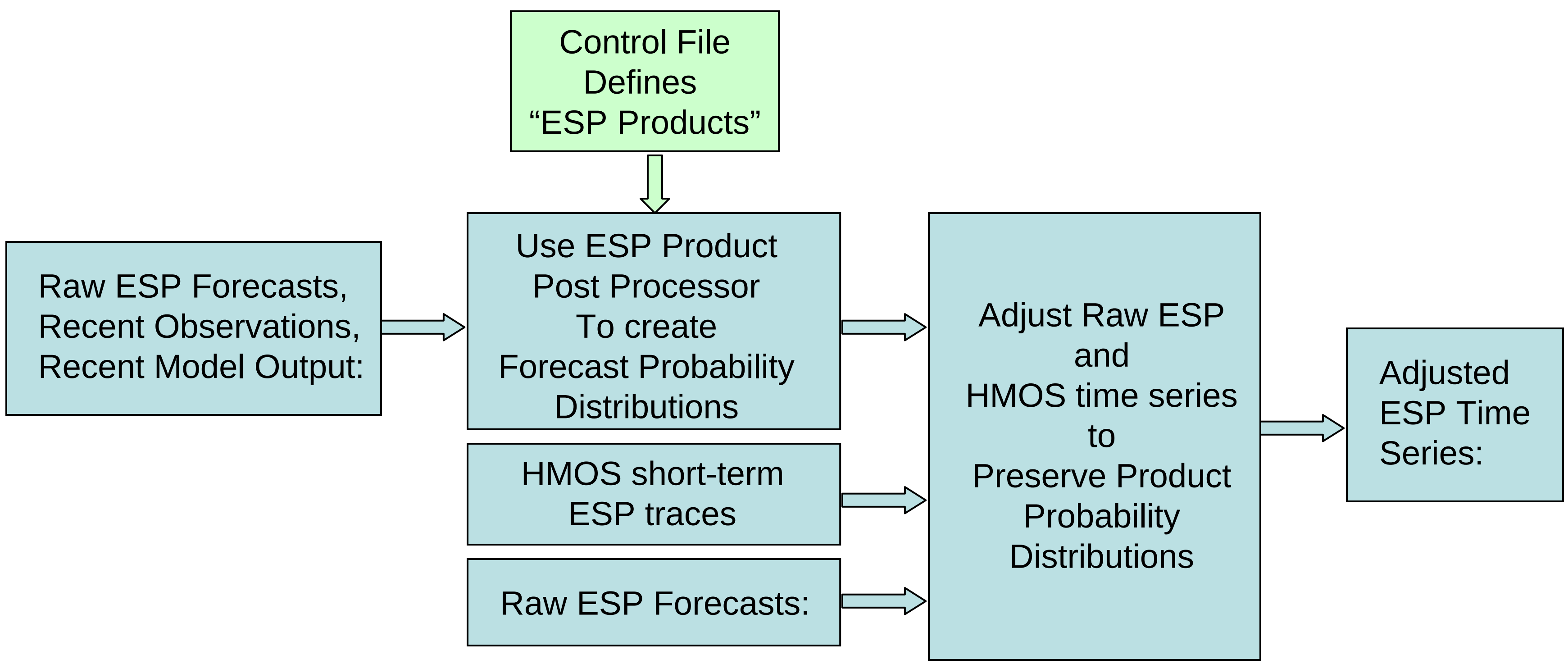
Analysis of Joint Relationship between Historical Model Simulation Results of Full Natural Flow and Observed Reservoir Outflow

Future Challenges

- Use recent observations and recent model output as additional input to the product generator
- Can we use the Ensemble Product PostProcessor to adjust individual ESP traces (preserving temporal scale-dependent uncertainty) by using the EPP strategy that applies multiple forecast distributions to adjust values of ensemble time series members?
  - Use ESP product post processor to create probability distributions for a set of prescribed products
  - Apply product forecast distributions and adjust values raw ESP time-series to be consistent with the product distributions
  - Combine ideas from other OHD studies (and others) to handle the case where the ESP output depends only on initial conditions.
- Multi-model applications (including use of regression-based water supply forecasts)?
- Alternative ways to evaluate Product Post-Processor integral equation to relax bivariate normality assumption?
- Approaches to smooth empirical distributions of observed and modeled values of streamflow products

ESP Time-Series Postprocessor Possible Science Strategy

- Two Step Process
  - Use ESP Product Post-Processor to create updated probability distributions of forecast “products”
  - Use “Schaake Shuffle” to create ensemble members that “preserve” all product probability distributions



Thank You