A Post-Processor for Hydrologic Ensemble Forecast Products

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Elements of a Hydrologic Ensemble Prediction System

QPE, QTE, Soil Moisture

Data Assimilator

Streamflow

Hydrology & Water Resources Models

Ensemble Pre-Processor

Ensemble Post-Processor

Parametric Uncertainty Processor

Hydrology & Water Resources Models

Ensemble Product Generator

Ensemble Product Post-Processor

Fig 1
CNRFC Ensemble Prototype
Locations

Smith River
Van Duzen River
Navarro River
Russian River
Salmon River
American River
(11 basins)
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. \( \text{ysim|fcst} \))
- 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. \( \text{yobs|ysim} \))
- If we neglect the uncertainty in the relationship between \( \text{yobs} \) and \( \text{ysim} \) that is caused by the uncertainty in the estimated forcing used to generate \( \text{ysim} \) during the forecast period, the pdf of \( \text{yobs} \), given the ensemble of precipitation and temperature forecasts can be estimated by the relationship:

\[
f(\text{yobs|fcst}) = \int_{0}^{+\infty} f(\text{yobs|ysim})f(\text{ysim|fcst}) \, dy\text{sim}
\]

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

- Raw ESP Forecast
- Adjusted ESP Forecast
- Re-adjusted ESP Forecast

ID = nfdc1
Forecast Day = 3/15
Forecast Period = 29 days
Nobs = 115

Kolmogorov Statistic = 0.030436
@ Forecast Probability = 0.7
Kolmogorov Test = Same
Critical Test Value = 0.39122
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
December 15: 29-day Calibration
December 15: 29-day Forecasts

**Raw and Adjusted Mean ESP Forecasts vs Observed**
- ID = crec1
- Forecast Day = 12/15
- Forecast Period = 29 days
- Nobs = 100
- Bias: Raw = 17.4777, Adjusted = 0.4437, Re-adjusted = 1.7178
- RMSE: Raw = 110.7125, Adjusted = 109.5902, Re-adjusted = 109.0081

**Cumulative Rank Histograms for ESP Forecasts**
- ID = crec1
- Forecast Day = 12/15
- Forecast Period = 29 days
- Nobs = 100
- Kolmogorov Statistic = 0.05
- @ Forecast Probability = 0.8
- Kolmogorov Test = Same
- Critical Test Value = 0.39122
December 15: 10-day Calibration

- Normal-Score Transform of Observations vs Simulations
  - ID = crec1
  - Forecast Day = 12/15
  - Forecast Period = 10 days
  - Nobs = 100
  - correlation = 0.96653

- Simulated and Adjusted Simulated vs Historical Observed Volumes
  - ID = crec1
  - Forecast Day = 12/15
  - Forecast Period = 10 days
  - Nobs = 100

- Climatological Distributions of Calibration Volumes
  - ID = crec1
  - Forecast Day = 12/15
  - Forecast Period = 10 days
  - Nobs = 100

- Graphs showing the comparison between observed and simulated data, with probability distributions for calibration volumes.
December 15: 10-day Forecasts

Raw and Adjusted Mean ESP Forecasts vs Observed

ID = crec1
Forecast Day = 12/15
Forecast Period = 10 days
Nobs = 100

- Raw
- Adjusted
- Re-adjusted

Bias: 18.3647, 4.118, 2.1777
RMSE: 105.3405, 107.8694, 98.6503

Cumulative Rank Histograms for ESP Forecasts

ID = crec1
Forecast Day = 12/15
Forecast Period = 10 days
Nobs = 100

- Raw ESP Forecast
- Adjusted ESP Forecast
- Re-adjusted ESP Forecast

Kolmogorov Statistic = 0.06
@ Forecast Probability = 0.7
Kolmogorov Test = Same
Critical Test Value = 0.39122
December 15: 3-day Calibration

![Graphs showing calibration results and distributions.](image)
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
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 Reservoir 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

Control File Defines “ESP Products”

Raw ESP Forecasts, Recent Observations, Recent Model Output:

Use ESP Product Post Processor To create Forecast Probability Distributions

HMOS short-term ESP traces

Raw ESP Forecasts:

Adjust Raw ESP and HMOS time series to Preserve Product Probability Distributions

Adjusted ESP Time Series:
Thank You