Ensemble Hydrologic Forecast Verification

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Forecast Verification

- **Comparisons** between *forecasts* and *observations*
  - Assess the attributes of the forecasting system (forecast quality)
  - Evaluate for use of forecasts in operational decision making (forecast value)
Steps in Verification

- Create a verification data set
  - Gather forecasts (f) and corresponding observations (x) over many realizations
- Examine the relationship between forecast-observation pairs
  - Summarize skill, bias, and other attributes of forecast quality
AHPS Verification System

Web-based tools for online access, analysis, and comparison of retrospective AHPS forecasts for River Forecast Centers (RFCs)

http://www.iihr.uiowa.edu/ahps_ver
Verification Data Archive
Verification Data Archive

Ensemble Streamflow Predictions

Retrospective forecasts for a 50-year period
Verification Data Archive

Conditional Distribution Forecast

- Retrospective forecasts for a 50-year period
- Processed ensemble forecasts & observations
Verification Data Archive

- Retrospective forecasts for a 50-year period
- Processed ensemble forecasts & observations
- Verification results
Ensemble Forecast Verification
Rules for Ensemble Verification

- Start with something simple
  - Transform ensemble forecasts into simpler forecasts
- Look before you leap
  - Do visual comparisons of forecasts & observations
- Measure once — cut into pieces
  - Decompose skill measures into related attributes
- Build on what you know
  - Synthesize results to the ensemble forecasts
Start with Something Simple

Transform into Event Forecasts
Ensemble Streamflow Forecast

Conditional Distribution Forecast

Des Moines River

Seasonal Flow Volume (cfs-days)

How many forecasts are shown here?

Transform ESP into a probability forecast for an event occurrence.
Look Before Your Leap

Graphical Comparison of Forecasts & Observations
Des Moines at Stratford, IA

Low-flow forecast
\[ p = P\{Y_i < 6000\} = 0.3 \]

Extreme Low-flow forecast
\[ p = P\{Y_i < 2230\} = 0.1 \]

\[ y_p = 6000 \text{ cfs-days} \]
\[ y_p = 2230 \text{ cfs-days} \]
Conditioned on Observed Flow

Des Moines River at Stratford (STRI4)

April 2\textsuperscript{nd}

Minimum 7-Day Flow

\( y_{0.1} = 2230 \text{ cfs-days} \)

\( y_{0.3} = 6000 \text{ cfs-days} \)
Low-Flow Event Forecasts

Minimum 7-Day Flow Volume (p=0.3)

April 2nd

Vertical lines show when event occurred

$f_i = P\{Y_i < 6000\}$
Conditioned on Forecast

Minimum 7-Day Flow Volume ($p=0.3$)

$\tilde{f}_i = P \{ Y_i < 6000 \}$

April 2nd
Measure Once — Cut to Pieces

Decompose skill measures into related attributes
Distributions-Oriented Measures

Skill Score Decomposition:

\[ SS_{MSE} = \rho_{fx}^2 - \left( \frac{\sigma_f}{\sigma_x} \right)^2 - \left( \frac{\mu_f - \mu_x}{\sigma_x} \right)^2 \]

- Potential Skill
- Slope Reliability
- Standardized Mean Error
Low-Flow Forecast

April 2nd

Minimum 7-Day Flow Volume ($p=0.3$)

$$f_i = P\{Y_i < 6000\}$$

$$SS = 0.578$$
$$PS = 0.601$$
$$CB = 0.017$$
$$UB = 0.005$$
Extreme Low-Flow Forecast

Minimum 7-Day Flow Volume ($p=0.1$)

$f_i = P\{Y_i < 2230\}$

$SS = 0.125$
$PS = 0.180$
$CB = 0.048$
$UB = 0.008$
Build on What You Know

*Synthesize Results to Ensemble Forecasts*
Des Moines River at Stratford

- Skill depends on the threshold
- Uncertainty varies by threshold and magnitude

Minimum 7-Day Flow
A Second Example

Des Moines River at Jackson
Ensemble Streamflow Forecasts

Minimum 7-Day Flow

April 2nd

Des Moines River at Jackson (JCKM5)

Forecasts tend to be much higher than the observations

Low-flow forecast:

\[ p = P\{Y_i < 545\} = 0.3 \]
Des Moines at Jackson

Minimum 7-Day Flow Volume ($p=0.3$)

April 2$^{nd}$

Observed Volume (cfs-days)

Probability Forecast ($f$)

$0.3$

Minimum 7-Day Flow

$f_i = P\{Y_i < 2230\}$

$SS = 0.312$
$PS = 0.441$
$CB = 0.009$
$UB = 0.119$
Des Moines River at Jackson

Reliability Diagram

- Shifted lines show high unconditional bias
- One-to-one slope indicates low conditional bias

$p = 0.3$

$P\{x = 1|f\}$

Perfect Reliability

No Resolution
Des Moines River at Jackson

Minimum 7-Day Flow

Impact on probability forecast skill

Unconditional biases degrade forecast skill
Using Verification to Improve Forecasts
Using Verification Archive

- Bias correction methods
- ESPADP error model
Bias-Corrected Jackson Forecasts

Skill Decomposition (Linear Model)

- April 2nd: Skill and PS significantly enhanced
- Unconditional bias completely eliminated

- Ability to do bias correction is automatic once a verification archive is produced

Minimum 7-Day Flow
Using Verification Archive

- Bias correction methods
  - ESPADP error model
- Optimal (Bayesian) forecasts

\[ p \{ x = 1 \mid f_i \} = p \times \frac{r(f_i \mid x = 1)}{s(f_i)} \]

- Posterior probability (reliability diagram)
- Prior probability (climatology)
- Bayesian update
Optimal Forecast

Des Moines River at Jackson (1950)

7-Day Low Flow (cfs-days)

Percent

Historical Climatology
Raw ESP
Bias-corrected
Bayesian forecast

IIHR
A Vision for the Future
Vision

- Generation and archival of retrospective forecasts will be a routine component of forecasting systems.
  - Verification methods can assess quality.
  - Archival information will form the basis for generating improved forecast products.