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Inflow Forecasting for Hydropower Operations: Bayesian Model Averaging for Postprocessing Hydrological Ensembles

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Introduction

- Inflow forecasting methods: ***Data-driven*** methods and ***physically-based*** methods
- Ensemble predictions are commonly used to assess the uncertainty of future inflow
- Ensemble predictions are often biased and have too small variance
- In this work we develop statistical postprocessing methods to obtain ***calibrated*** and ***sharp*** probabilistic forecasts

Bayesian Model Averaging (BMA)

$$f(y|x_1,...,x_M) = \sum_{m=1}^{M} \frac{1}{w_m} g(y|x_m)$$

$$Y|x_m \sim \mathcal{N}(\mu_m, \tau^2)$$

$$\mu_m = \alpha_m + \beta_m x_m$$

— Y: Random quantity of interest

— $x_m,\ m = 1, ..., M$: Deterministic predictions

— $f(y|x_1, ..., x_M)$: Predictive distribution, given M predictions

— $g(y|x_m)$: Pdf associated with with member m

— w_m: Weight associated with member m

— α_m and β_m : Bias correction parameters for member m

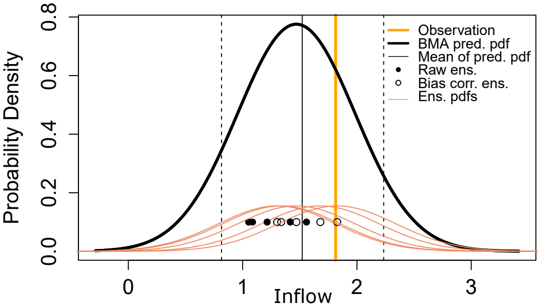
— τ : Standard deviation of the ensemble member pdfs

BMA with exchangeable ensemble members

$$f(y|x_1, ..., x_M) = \frac{1}{M}\sum_{m=1}^{M} g(y|x_m)$$

$$Y|x_m \sim \mathcal{N}(\mu_m, \tau^2)$$

$$\mu_m = \alpha + \beta x_m$$



Applications and earlier work

• Temperature forecasting
Raftery, Gneiting, Balabdaoui, and Polakowski (2005)

• Precipitation forecasting
Sloughter, Raftery, Gneiting, and Fraley (2007)

• Wind speed forecasting
Sloughter, Gneiting, and Raftery (2010), McLean Sloughter, Gneiting, and Raftery (2013)

• Inflow forecasting
Duan, Ajami, Gao, and Sorooshian (2007), Vrugt and Robinson (2007), Todini (2008), Rings, Vrugt, Schoups, Huisman, and Vereecken (2012)

Bayesian Model Averaging using Varying Coefficient Regression (BMA-VCR)

BMA

$$f(y|x_1, ..., x_M) = \frac{1}{M}\sum_{m=1}^{M} g(y|x_m)$$

$$Y|x_m \sim \mathcal{N}(\mu_m, \tau^2)$$

$$\mu_m = \alpha + \beta x_m$$

BMA-VCR

$$f(y|x_1, ..., x_M) = \frac{1}{M}\sum_{m=1}^{M} g(y|x_m)$$

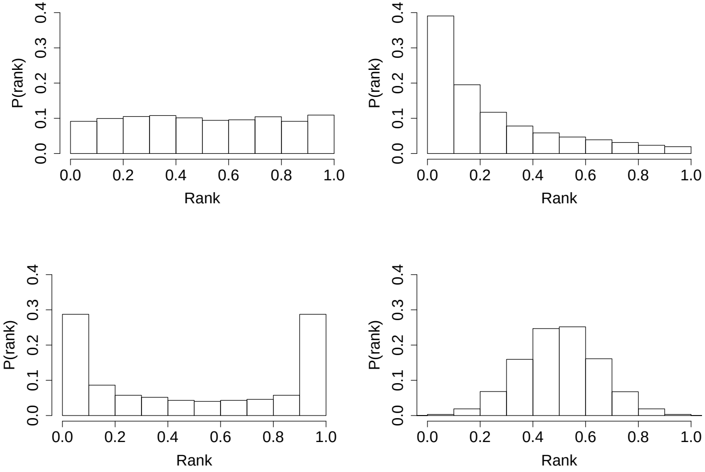
$$Y|x_m \sim \mathcal{N}(\mu_m, \tau^2)$$

$$\mu_m = (\alpha + \alpha_t) + (\beta + \beta_t)x_m$$

$$\alpha_t = \alpha_{t-1} + a_t, \quad a_t \sim N(0, \delta^{-1})$$

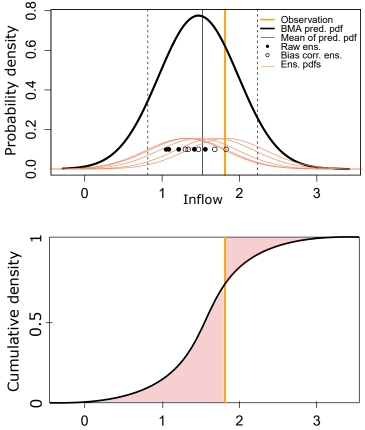
$$\beta_t = \beta_{t-1} + b_t, \quad b_t \sim N(0, \delta^{-1})$$

Evaluation of probabilistic forecasts: Calibration

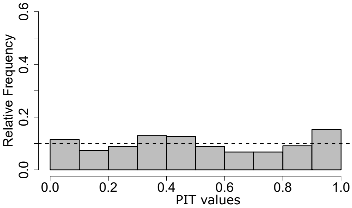


Evaluation of probabilistic forecasts: Sharpness

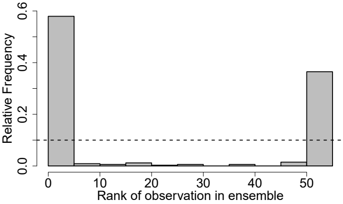
- Continuous ranked probability score (CRPS)
- Comparable to absolute error for deterministic forecasts
- For a perfect deterministic forecast, the CRPS is zero



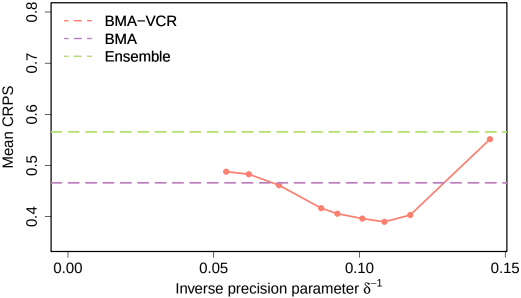
Results



Relative Frequency
0.0
0.2
0.4
0.6
0.0
0.2
0.4
0.6
0.8
1.0
PIT values



Relative Frequency
0.0
0.2
0.4
0.6
0
10
20
30
40
50
Rank of observation in ensemble



BMA−VCR
BMA
Ensemble
Mean CRPS
0.4
0.5
0.6
0.7
0.8
0.00
0.05
0.10
0.15
Inverse precision parameter δ^{-1}

Conclusions and future work

- We have presented a statistical postprocessing method based on BMA
- Demonstrated good results based on real data for low lead times
- For higher lead times, consider alternative pdfs associated with the ensemble members, e.g. a combination of beta distributions and the empirical distribution of historical inflow values
- Extend the method to a higher-dimensional system

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