Supporting Pakistan's water allocation decisions through improved seasonal streamflow forecasts

Reliable seasonal streamflow forecasts are critical for the efficient allocation of water resources in the Indus Basin Irrigation System of Pakistan. CSIRO explores the potential of a Bayesian joint probability (BJP) modelling approach for seasonal forecasts of inflows to Tarbela and Mangla dams, using predictors accounting for antecedent basin conditions and large-scale climate drivers.

RATIONALE AND METHODOLOGY

A reliable understanding of future seasonal water availability in Pakistan is critical given highly seasonal flows, limited storage capacity (30 days of supply) and increasing water demand for agriculture and energy production. The ability to forecast supply at the beginning of the Kharif (summer season) would improve water allocation planning in the Indus Basin Irrigation System. We apply the BJP forecast approach that uses Bayesian inference to determine the optimal relationship between multiple predictors and the predictand using a joint multivariate normal distribution in transformed space [1,2]. Calibration uses leave-one-out cross validation (i.e. for each year, calibration uses all other year's data) to reduce the possibility of artificial skill due to overfitting. Forecast performance is assessed using a range of diagnostic plots and skill score comparisons.

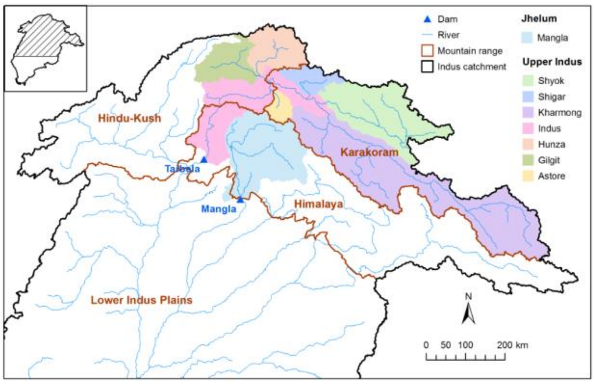

Figure 1 Upper Indus basins showing locations of dams

APPLICATION

The BJP has been applied to seasonal flow forecasting for the Indus at Tarbela and the Jhelum at Mangla dams (Figure 1) using 1975–2015 flow data. Results for Kharif (April-September) and Early Kharif (April-June) are highlighted. For Jhelum, an additional forecast approach is the Snowmelt Runoff Model (SRM) that uses observed inputs to determine conditions at the beginning of the Kharif and a scenario approach to produce a forecast distribution. Due to its more intensive data requirements SRM can only be applied from 2000 onwards. The SRM is calibrated using data for 2003–2010 without cross-validation. Results (not shown) indicate SRM forecasts are not as robust as BJP forecasts outside of this calibration period.

A detailed literature review [3] investigated the drivers of flow variability and correlation analysis was used to quantify the strongest relationships, enabling an informed selection of candidate predictors for input to the BJP. Two classes of predictors were investigated, those related to antecedent catchment conditions preceding the forecast season (flow, snow cover area) and those related to large-scale climate drivers influencing precipitation and temperature prior to and during the forecast season (e.g. North Atlantic Oscillation, El Nino Southern Oscillation). Flow in the month preceding the forecast season and a measure of ENSO prior to the forecasting season were consistently selected as predictors.

For Jhelum at Mangla, an ENSO index preceding the Kharif season was a preferred predictor. For Indus at Tarbela, ENSO in the May-June period the prior year gave the best performance. We suggest this earlier ENSO signals snow pack build-up over the autumn and winter seasons prior to Kharif, given the May-June flows at Tarbela are dominated by snowmelt.

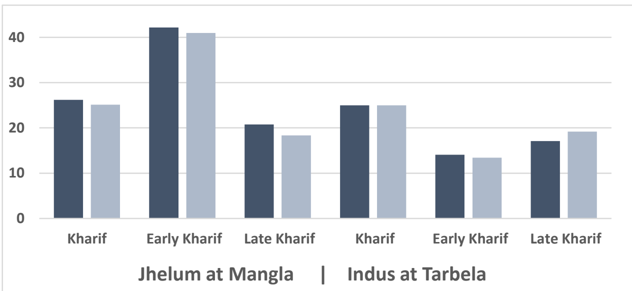

Figure 2 BJP cross-validated skill scores, % skill gain relative to climatology, for CRPS (blue) and RMSE (grey) skill scores

Two skill scores are used to compare forecast skill of BJP models using different predictor inputs. The continuous ranked probability score (CRPS) assesses the reduction in error across the whole forecast probability distribution and the root mean squared error (RMSE) assesses the forecast median. Figure 2 compares the relative performance across the study basins and seasons.

Diagnostics used to assess performance of selected BJP models are shown in Figure 3. Probability integral transforms (PIT) plots assess whether there are biases in the forecasts or whether the forecast probability distributions are too wide or narrow. These plots confirm the BJP forecasts are reliable and robust across time and magnitude of flow.

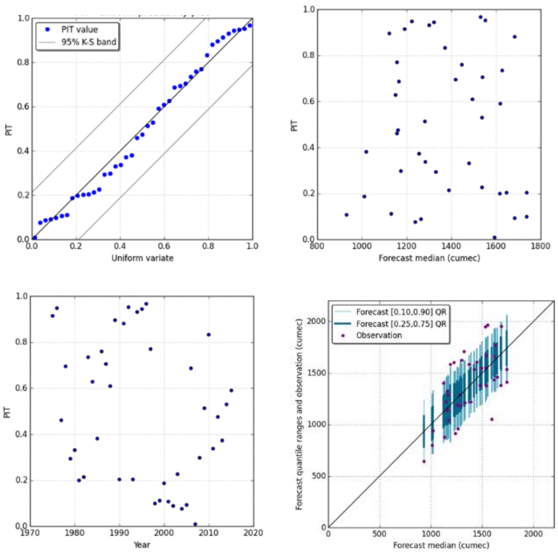

Figure 3 Cross-validation plots for Jhelum at Mangla, Kharif

Examples of the performance of the BJP forecasts are shown in Figure 4 for Jhelum for Kharif season forecasts. The time-series show the range (25^{th} to 75^{th} for the thicker lines and 10^{th} to 90^{th} percentile for the finer lines) of 1000 BJP forecasts generated probabilistically for each year based on the cross-validated calibration (i.e. not using the forecast year's data). The histogram shows the cross-validated BJP and climatological distribution of forecast flows for an example year, 2015. For this year it is clear that the BJP forecasts outperform climatology.

Australian Aid

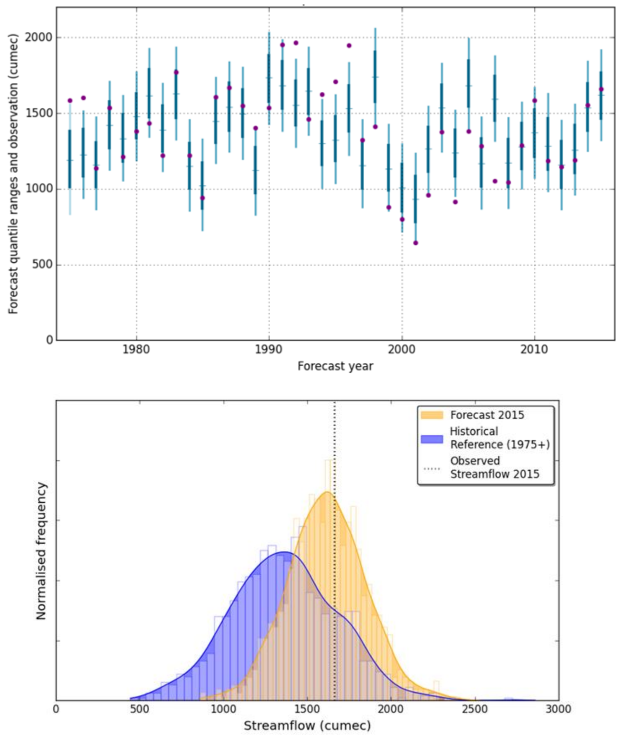

Figure 4 Time-series of forecasts (range) versus observations (top) and 2015 histogram of forecast versus climatology (bottom) for Jhelum Kharif cross-validated BJP forecasts

CONCLUSIONS

The BJP shows promise as a seasonal forecasting tool suitable for Kharif flows for the study basins. It is quick and relatively simple to calibrate to different basins, in contrast to SRM with its intensive calibration and data requirements. Further research will investigate its performance for all major sub-basins of the Upper Indus.

ACKNOWLEDGEMENTS

We thank WAPDA-GMRC for sharing datasets and the SRM for this collaborative work. A special thanks to Danial Hashmi for sharing his advice and expertise.

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ACKNOWLEDGEMENTS

This fact sheet designed and implemented by CSIRO contributes to the South Asia Sustainable Development Investment Portfolio and is supported by the Australian Government.

FOR FURTHER INFORMATION

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