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From surface runoff to streamflow: An application of statistical post-processing for seasonal streamflow forecasting

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Abstract: The Australian Bureau of Meteorology has embarked on a 10-year research plan focused on Earth System Modelling. A unified modelling system supporting all forecast products and services will drive efficiency gains, improve product consistency and remove the maintenance burden of disparate systems now in operation. A physically based hydrological model will underpin the two seasonal hydrological forecasting services provided by the Bureau: The Australian Water Outlook (AWO) and the Seasonal Streamflow Forecasting (SSF) service. Currently each service is supported by a separate forecasting system. The AWO service provides seasonal forecasts of root-zone soil moisture, runoff and AET using the Australian Water Resources Assessment model (AWRA). AWRA is a 5km2 distributed land surface model and underpins the AWO. Calibrated ACCESS-S (vS2) seasonal climate forecasts provide the necessary climate forcing. The current Seasonal Streamflow Forecasting (SSF) service provides forecasts at discrete point-locations that coincide with river gauging stations and major water storages. Seasonal streamflow forecasts are based on a Bayesian Joint Probability (BJP) statistical model that relates current catchment conditions (antecedent observed monthly flow, Qobs) and the current climate state (climate indices) to the likely streamflow in a forthcoming three-month period.

To integrate the two services, BJP post-processing is instead applied to AWO seasonal forecasts to generate seasonal streamflow forecasts. The BJP statistical model provides the *joint probability* of simultaneous outcomes (streamflow at three monthly lead-times) given a set of defined input variables. Separate statistical models are defined for each month of the year at up to 481 forecast locations (site-month pairs). Statistical post-processing is applied to both root-zone soil-moisture (conceptually equivalent to catchment antecedent conditions) and runoff (conceptually similar to river discharge, albeit in error and requiring a form of error correction). Forecast skill, calculated as the Cumulative Rank Probability Skill-Score (CRPS-S), is then compared to forecast skill obtained from a benchmark model: use of observed antecedent streamflow (Qobs) only to predict streamflow.

Median forecast skill is maximised if the AWO forecast variable with the highest forecast skill is selected for each site-month combination. For each month of the year, median forecast skill is either statistically equivalent to or significantly increased from the benchmark model. A threshold of +/- 5% CRPS-S around the benchmark model forecast skill reveals ~66% site-month combinations show either an equivalent forecast skill or increased forecast skill compared to the benchmark model. Similarly, a threshold of [-5%, +5%] defined as forecast skill equivalent to a historical climatology reveals 90% of site-month combinations have either an equivalent or positive forecast skill.

Streamflow post-processed forecasts perform particularly well during high-flow seasons, where rainfall is perhaps the predominant input forcing that elicits a hydrological response. Conversely forecast performance drops during the low-flow seasons in certain regions (e.g. SW WA and the northern Australia), where rainfall perhaps ceases to significantly impact streamflow and other hydrological processes predominate. These hydrological processes may be absent in AWRA, thus resulting in little inter-annual variation during the low-flow season in either root-zone soil-moisture or runoff. Due to hydrological persistence, observed antecedent conditions provide a particularly high-level of forecast skill during the low-flow season. The spatial and seasonal variation in which either root-zone soil-moisture or runoff maximises forecast skill remains a subject of investigation. This study demonstrates a comparable level of forecast skill between statistical post-processing of AWO seasonal forecasts and the current operational service. Acceptable forecast skill is possible without a dependency on Qobs.

Keywords: *Distributed and catchment hydrological modelling, seasonal hydrological ensemble forecasting, forecast post-processing*