25th International Congress on Modelling and Simulation, Darwin, NT, Australia, 9 to 14 July 2023
mssanz.org.au/modsim2023

Variable storage capacity in hydrological models to enhance performance under contrasting climates

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Abstract: This study demonstrates the application of a simple, generalisable modification of bucket-type hydrological models to improve their ability to perform under contrasting climate conditions. In particular, we systematically vary the size of each models' production store as a function of recent observed climate, in order to simulate changing connectivity between surface and stored water during long periods of drought. We test these modifications on five rainfall-runoff models in 155 catchments in Victoria, achieving a significant reduction in simulation bias. Many of these catchments underwent significant hydrological shifts during the Millennium drought (MD) which traditional hydrological models struggle to accurately capture, leading to large errors in simulation, especially due to overestimation of streamflow during the years of the drought.

The underlying mechanisms behind these shifts in hydrological behaviour are still uncertain, but many studies suggest a predominant role of catchment storage dynamics in changing the partitioning of precipitation into runoff. Previous modelling studies have leveraged this to improve model reliability during the drought, experimenting with various model modifications such as deficit formulations or long-memory storages. However, these approaches have relied on the modification of models' constitutive equations, which limits their generalisation since bespoke changes to individual models are required. To our knowledge, there is no research that has tested these approaches on many models at once.

Our approach, instead, is based on the observation of changed recession behaviour during and after the drought, suggesting changes in the level of connectivity between stored water and the stream. We simulate this by allowing models' storage capacity to vary as an exponential function of the past climate and seasonality. This approach requires two additional parameters per model (number of lookback years and strength of the exponential relation) and is more generalisable as it does not require modification of the models' equations. We test the modified models by forcing them to compromise between performance in two climatically contrasting periods with a single parameter set. This was achieved by calibrating models on the average of two objectives: one calculated between the years 2000 and 2009 (i.e. the MD) and one on the wettest continuous 10 year period in each catchment. The objective function used for each period is heavily bias penalised in an attempt to minimise the errors in streamflow volumes commonly observed during the drought.

The results of our calibrations indicate that by changing the available storage size depending on recent climate, generally by increasing it during dry periods and vice versa, the modified models are much more able than their unmodified counterparts to produce unbiased streamflow estimates in each of the two calibration sub-periods with a single parameter set (Figure 1). These results suggest a simple yet promising trajectory towards the development of more flexible hydrological models, fit for a changing world, and will therefore contribute towards the next generation of hydrological models.

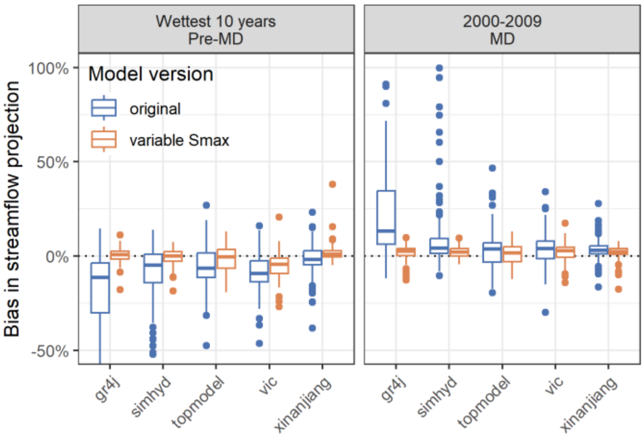

Figure 1. Comparison of bias in each calibration sub-period for original and modified models

Keywords: *Hydrological models, climate variability, Millennium drought, model reliability, model improvements*