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Tailored calibration of stochastic weather generators for enhanced hydrological system evaluation

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Abstract: Stochastic weather generators (SWGs) are widely used in climate impact assessments across a range of sectors including water resources, flood risk, agriculture, and renewable energy. However, *conventional* approaches to calibrating SWGs, such as the Method of Moments (MoM) and Maximum Likelihood (ML), often results in these SWGs falling short in capturing important features of climate, such as extremes and changes relevant for impact assessment. This study explores the use of *tailored* calibration approaches, specifically the Simulated Method of Moments (SMM), to improve the ability of SWGs to simulate important climate attributes. We demonstrate the value of SMM in capturing both historical and future climate extremes, highlight the necessity of robust optimisation, and assess the implications for hydrological responses to rainfall.

We use the tailored SMM approach to calibrate the WGEN stochastic rainfall generator, with hydrological responses evaluated via the GR4J rainfall-runoff model across three catchments in New South Wales and the ACT. We prioritise multi-day rainfall extremes in the tailored calibration, as it is an important driver of hydrological response.

The results in Figure 1 show that while a conventional calibration approach (based on MoM/ML) captures total rainfall reasonably well (Figure 1a, green), it underestimates historical extreme multi-day rainfall by around 30% for the three catchments (Figure 1b). These biases in rainfall propagate through the hydrological model, resulting in substantial underestimation of streamflow, particularly for high-flow events, where biases range from 30% to 50% across the catchments (Figure 1d). In contrast, tailored calibration substantially reduces these biases, producing rainfall simulations that align more closely with observed extremes and simulated streamflow metrics more in line with those obtained using observed rainfall.

We further demonstrate the importance of using robust optimisation with the tailored SMM approach. A climate stress-testing experiment reveals that standard optimisation techniques such as Nelder-Mead and Shuffled Complex Evolution (SCE) can introduce substantial errors (up to 20%) in calibrated climate attributes. In comparison, the Robust Gauss-Newton (RGN) algorithm (Qin et al. 2022) significantly reduces these errors and decreases uncertainty in projected streamflow by up to 75% for a given change in the targeted climate features.

These findings underscore the potential of tailored calibration methods to enhance the accuracy and relevance of SWGs in climate impact modelling. By enabling users to prioritise key climatic attributes—such as extremes—and apply robust optimisation, this approach offers a more flexible and powerful framework for supporting water-related decision-making under climate variability and change. Further details on this work can be found in McInerney et al. (2025).

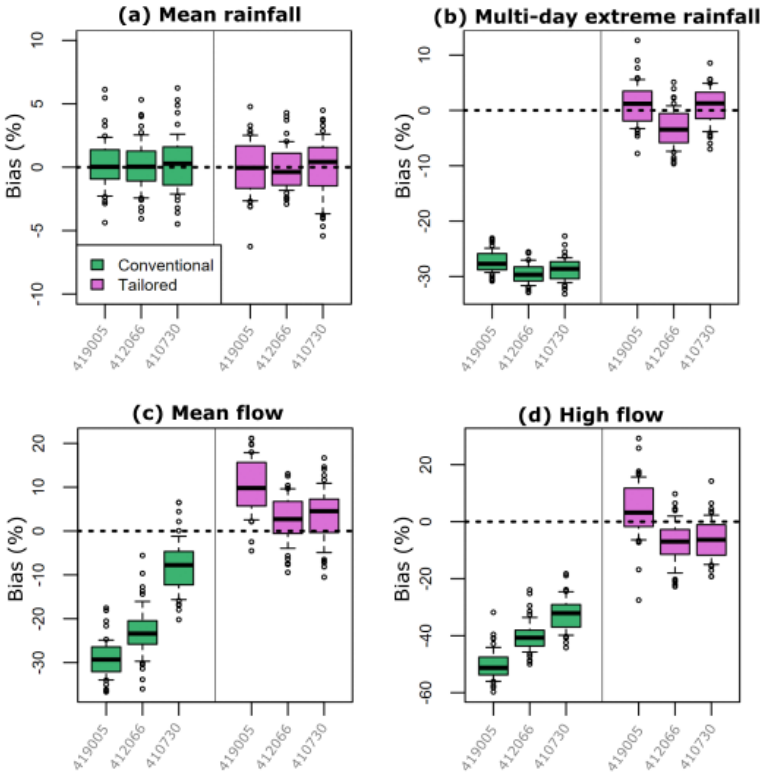

Figure 1: Comparison of conventional (MoM/ML) and tailored (SMM) calibration approaches. Panels (a–b) show biases in mean and extreme (99th percentile, 3-day) rainfall. Panels (c–d) show resulting biases in mean and high (99th percentile) simulated streamflow. Boxes represent simulated climate attributes across catchments.

Keywords: *Stochastic weather generators, tailored calibration, Simulated Method of Moments (SMM), Robust Gauss-Newton, climate impact assessment, extreme rainfall*

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