EGU21-13062
https://doi.org/10.5194/egusphere-egu21-13062
EGU General Assembly 2021

Advances and challenges in the past decade: from univariate to multivariate bias adjustment of climate models for impact studies

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Climate models are primary tools to reconstruct past and predict future climates. It is common procedure to use general circulation models (GCMs) for large scale studies and regional climate models (RCMs), for impact studies at a finer spatial resolution. However, climate models face biases compared to observation. To overcome these biases, different statistical methods have been suggested in the scientific literature that employ a transformation algorithm to re-scale (or bias-correct) RCM outputs. Some of these methods (e.g. univariate methods that adjust only one RCM-simulated variable at a time) are comparatively easy to implement while others (e.g., multi-variate correction that guarantees consistency in spatiotemporal fields and different climate variables) that have been introduced lately to the field, are more complex and require advanced statistical knowledge and more computing power. Therefore, the need to further investigate the performance of the latest more complex bias-adjustment methods under different climatic conditions still exists and their added value still needs to be evaluated from different aspects.

Thus, we assessed the skill of two commonly used multivariate methods, namely copula based bias adjustment methods and non-parametric n-dimensional multivariate bias correction (MBCn). We further compared them with widely used univariate methods, i.e. the parametric distribution mapping (DS) and the non-parametric quantile delta mapping (QDM), to adjust RCM-simulated temperature and precipitation. We evaluated these methods over 55 Swedish catchments varying in size and climatic features using an ensemble of 10 different RCMs under varying climate conditions to check multiple features that represent both probabilistic and temporal behavior. To evaluate how these methods, perform in nonstationary climate conditions, we performed the assessment over two periods of 22 years each, where the period 1961-1982 is used for calibration and 1983-2004 for validation. The adequacy of each bias adjustment method in reducing the biases varies depending on several factors such as the studied watershed, the applied RCM model, utilized climate variable and the statistical feature that is subjected to adjustment. We further discuss potential issues and trade-offs of each of the applied methods and present an evaluation of each bias-corrected climate variable in terms of its (1) statistical properties, (2) temporal behavior utilizing cross correlation and autocorrelation measures, and (3) dependence structure to the other variable with help of copula-based dependence measures. Finally, we also examined how the four bias-adjustment methods influence the Clausius Clapeyron relation, which serves as

an important climatic illustration of the relationship between extreme precipitation and temperature.