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What are climate models and how can we improve their accuracies for climate impact studies?

Background

Climate models, sometimes called the general circulation models (GCMs) illustrate energy and matter interaction in different parts of the ocean, atmosphere and land using mathematical equations. After a climate model is initiated, it undergoes a testing phase. This is done by assessing the model performance and accuracy from the current time backwards into the historical time based on the observed climate and weather conditions. GCMs are used to project the future climate based on different scenarios e.g. land use change, human population growth, economy evolution, and the atmospheric greenhouse gases emissions.

However, these GCMs have coarse resolutions and regional biases which make it difficult to meet the requirement of many users demanding high-resolution outputs to produce regional to local-scale climate projections as well as climate impact studies. Therefore, there is a need to accurately correct these biases inherent in GCMs and examine the abilities of these correction techniques in replicating the observed climate change signals at the local scale.

A univariate bias-correction (BC) method corrects biases in individual climate variables at a time. However, the dependencies and correlation between the different variables are disregarded. In multivariate BC, multiple climate variables are corrected concurrently either by considering the whole multivariate dependence structure or assuming stationarity in the temporal sequence of model variables.

Climate model biases and uncertainties: challenges in bias-correcting climate models for reliable climate impact studies

This study assesses the performance of two univariate and three multivariate bias-correction (BC) methods in reproducing the observed maximum temperature distribution as well as the temperature variability over the basin using eight climate models and the mean of the original model simulation (model ensemble mean) at the historical (1975-2005) and future period (2020-2050) under two $C0_2$ emission scenarios for annual, dry and wet periods. Results show that the uncorrected (raw) climate model output performs poorly in replicating the site-specific temperature variability and the observed trend over the basin for all seasons. Due to the time-independent error component of the climate models, the modelled climate change is generally incorrect. This is evident in the trends presented in the uncorrected model – as it constantly shows no definite trend pattern. However, the BC model provides a worthy output similar to the observation which buttresses the need for correcting biases in climate models before it can be used for impact studies. Overall, the multivariate methods correct the dependence structure of different climate variables, thereby, providing a general-purpose methodology to the climate community. This is most essential for most impact studies like drought monitoring, hydrological modelling, e.t.c. Although the multivariate BC methods correct the inter-variable dependence structure, due to its complex algorithm and iteration sequence, it is time-consuming and computationally expensive. However, it can be used directly in downscaling applications contrary to critiques on univariate BC methods. Furthermore, the energy distance, a metric that measures the distance between the distributions of random vectors. This provides concise information on the performance and stability of multimodel-multivariate BC method and is recommended for picking between climate models and BC algorithms. Energy distance is zero if the distributions are identical, thus signifying equality of distributions.

Bias-corrected models suitably replicate observed regional to local scale effects of climate change

Based on the corrected model, there is a positive temperature trend in most parts of the basin, however, with increased magnitudes in the future. The warming climate will intensify the effects of drought on water demand and supply by natural systems and humans. Additionally, high temperatures could intensify convective precipitation. This, coupled with human activities will affect the food chain balance, water quality and river's biodiversity. Therefore, there is a need for an accurate understanding of the historical climate as well as a correcting the biases in the representation of the historical and future basin's hydro-climatological features as a result of climate model biases. This is necessary for appropriate adaptation and mitigation practises to combat climate change and extremes in the basin and the region in general.

Based on Journal Article*: "Multiple bias-correction of dynamically downscaled CMIP5 climate models temperature projection: a case study of the transboundary Komadugu-Yobe river basin, Lake Chad region, West Africa*"

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