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Projections of future rainfall for the upper Ping River Basin using regression-based downscaling

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Abstract

The objective of this study was to use regression modelling, a form of statistical downscaling technique, to predict the daily rainfall occurrence and rainfall amounts for a small river basin, the upper Ping River Basin (UPRB) in northern Thailand. Daily historic (1960–2005) rainfall and a number of daily reanalysis variables (NCEP/NCAR) were used to create regression models that estimate the probabilities of rainfall occurrence (wet days) and amounts (rainfall depth) at each of 29 rain gauge stations located in and around the UPRB. The regression models were calibrated using historic (1960–1989) data and validated using historic (1990–2005) data. Regression models were later applied to historic (1960–2005) GCM outputs (MPI-ESM-LR model) which were adjusted to correspond to the selected reanalysis variables using the Nested Bias Correction (NBC) technique. Rainfall occurrence and amounts were predicted for the periods 2006–2050 and 2051–2100 for RCP2.6, RCP4.5, RCP8.5 scenarios. Results show that the effects of climate change vary considerably across the catchment, with significantly declines in both the number of wet days and rainfall depth in the wet- and especially the dry-season in the middle of the catchment but obviously increase slightly towards the northern part of the catchment. Since the stepwise regression was used to select the atmospheric variables to form the regression models for simulating rainfall occurrence and amount, different stations have their own predictors and can influence future rainfall to vary significantly between 29 rain gauge stations. If the top three predictors were selected to form the regression models for simulating rainfall occurrence and amount for all stations, the future rainfall characteristics possibly change and can be used to compare with those of presented in this study. It will show either atmospheric predictors or climate change scenarios would have more effect on future rainfall characteristics.

Keywords: Statistical downscaling; Nested bias correction; MPI-ESM-LR model; Representation concentration pathways (RCPs); Ping River Basin

1. Introduction

An assessment of climate change impacts on hydrological studies requires outputs of experiments from General Circulation Models (GCMs). However, the GCMs are constrained by their coarse spatial resolution to be used for resolving local scale hydrological processes (Wilby and Wigley, 1997; Wilby et al., 1999; Timbal et al., 2009). Downscaling techniques have therefore emerged to relate the regional scale atmospheric variables to the local scale surface variables. Downscaling approaches can be separated into two categories; dynamical and statistical techniques. Strengths and weaknesses of these two downscaling categories are clearly presented by Wilby et al. (2002). In dynamic downscaling referred to as the Regional Climate Models (RCMs), the time-varying atmospheric conditions supplied by GCMs are used to drive a regional, numerical model in higher spatial resolution (tens of kilometres) to simulate local conditions in greater details. On the other hand, a statistical downscaling establishes a statistical relationship from observations between large scale variables and a single local variable and then subsequently

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applies the developed relationship on the scenario GCM outputs to obtain a range of local variables. Statistical downscaling can be distinguished into three approaches: weather classification schemes, stochastic weather generators, and regression models (Wilby et al., 2004). Regression models have been used by several scientists to simulate future rainfall projections using either linear or nonlinear relationship between local scale surface variables and atmospheric variables (Wilby and Wigley, 1997; Wilby et al., 1999; Dettinger et al., 2004; Feng et al., 2014). Regression-based approach was also successfully applied for simulating daily rainfall occurrence and amount in the Yangtze River Basin (Guo et al., 2012), Godavari River basin in India (Das and Umamahesh, 2016) and 60 stations in South Korean (Min et al., 2011). Yhang et al. (2017) compared the performances of different downscaling methods, focusing on East Asian summer monsoon. The dynamical downscaling was conducted by the Regional Model Program (RMP) of the Global/Regional Integrated Model system (GRIMs), while the statistical downscaling was performed through coupled pattern-based simple linear regression. A combination of dynamical and statistical downscaling has shown to produce the best results of simulating the precipitation in both time and space.

Statistical characteristics of the reanalysis data and the GCM outputs at the corresponding location and period used for generating the regression relationships are normally different. Bias correction technique is therefore usually applied for adjusting these differences. The simplest bias correction method focuses on the monthly mean difference between these two data types (Graham et al., 2007). Haerter et al. (2011) recommended that the differences of the standard deviation (STD) should also be considered together with the mean differences to be able to significantly reduce the statistical differences between the simulated (GCMs) and observed (reanalysis) data. However, Johnson and Sharma (2009) proposed a method called a Nested Bias Correction (NBC) which involved nesting the GCM simulations into monthly and annual time series of observed data, such that monthly and annual means, variances and lag correlations are appropriately simulated. The NBC has proved to provide better performance in terms of prediction error at annual and inter-annual time scales compared to a simple monthly correction method (considering only the differences of means and STD of the two data types). Moss et al. (2010) also suggested that these RCPs scenarios can provide a framework for modeling in the next stages of scenario-based research that will yield valuable insights into the interaction of natural and human-induced climate processes.

Rainfall changes in the upper Ping River Basin (UPRB) would affect runoff flowing into the Bhumibol Dam, the major dam which delivers the water supply for all sectors for the lower Chao Phraya River Basin where Bangkok—the capital city—is located at the downstream of the UPRB. For water resources management of the dam and for finding suitable measures to mitigate water resources problems arising from changes in climate conditions, it is important to estimate future changes in rainfall in UPRB.

According to the flexibility, ease of implementation and low computation requirements of the regression-based approach (Wilby et al., 2004), regression models were used in this study to analyze the future effects of climate change on future rainfall at 29 locations within the UPRB and its surrounding. The NBC and Simple Bias Correction (SBC) were applied to the selected GCM predictors to calculate the bias correction factors to be used for adjusting the scenario GCM outputs. The RCPs scenarios from MPI-ESM-LR model developed under the phase five of the Coupled Model Intercomparison Project (CMIP5) by Max Planck Institute for Meteorology (MPI-M), Germany, were applied to simulate future rainfall occurrence and amounts.

2. Study area and data

2.1. Study area

The UPRB is situated 17°14′30″−19°47′52″N, 98°4′30″−99°22′30″E in Chiangmai and Lamphun province in northern Thailand (Fig. 1) (Mapiam et al., 2014). The UPRB is separated from the lower Ping River Basin (LPRB) by the Bhumibol Reservoir, which has an active storage capacity of 9.7×10^9 m^3. The Ping River, flowing along these two river basins, is one of the main tributaries of Chao Phraya, the largest river basin in Thailand, which drains more than one-third of the country's land area.

2.2. Rainfall data

Daily rainfall occurrence and amounts observed at the 29 stations by the Royal Irrigation Department (Fig. 1) were used to relate to the reanalysis variables to form the regression relationships. The 22 stations with an index starting by 07 and 17 are located in Chiang Mai and Lumphun province, respectively, while the 7 stations with an index starting by 20, 16 and 63 are located in Mae Hong Son, Lampang, and Tak province, respectively. These rainfall stations were selected according to their availability of the data for more than 96% during the study period (1960−2005).

2.3. Reanalysis data

Reanalysis grid point data (2.5° × 2.5°) on a daily basis in 1960−2005 provided by the National Centers for Environmental Prediction/Nation Center for Atmospheric Research (NCEP/NCAR), USA, available at http://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis.html (Kalnay et al., 1996) were utilized for the study.

2.4. General circulation model (GCM) outputs

The GCM outputs (1.875° × 1.875°) on a daily basis simulated using the MPI-ESM-LR model developed under CMIP5 by MPI-M, Germany (available at http://esgf-data.dkrz.de/esgf-web-fe/) were selected for the study. In this study, GCM outputs used are separated into 2 datasets. The