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Review papers

Projected changes in precipitation and temperature over the Canadian Prairie Provinces using the Generalized Linear Model statistical downscaling approach

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S U M M A R Y

In this study, a multisite multivariate statistical downscaling approach based on the Generalized Linear Model (GLM) framework is developed to downscale daily observations of precipitation and minimum and maximum temperatures from 120 sites located across the Canadian Prairie Provinces: Alberta, Saskatchewan and Manitoba. First, large scale atmospheric covariates from the National Center for Environmental Prediction (NCEP) Reanalysis-I, teleconnection indices, geographical site attributes, and observed precipitation and temperature records are used to calibrate GLMs for the 1971–2000 period. Then the calibrated models are used to generate daily sequences of precipitation and temperature for the 1962–2005 historical (conditioned on NCEP predictors), and future period (2006–2100) using outputs from five CMIP5 (Coupled Model Intercomparison Project Phase-5) Earth System Models corresponding to Representative Concentration Pathway (RCP): RCP2.6, RCP4.5, and RCP8.5 scenarios. The results indicate that the fitted GLMs are able to capture spatiotemporal characteristics of observed precipitation and temperature fields. According to the downscaled future climate, mean precipitation is projected to increase in summer and decrease in winter while minimum temperature is expected to warm faster than the maximum temperature. Climate extremes are projected to intensify with increased radiative forcing.

Contents

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1. Introduction

The Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (IPCC, 2013) demonstrates that the global climate is warming and most of the observed changes are likely due to increases in the concentration of anthropogenic greenhouse gases (GHGs). The impacts of a warming climate on global and regional water resources are many and have been re-emphasized recently (e.g., Arnell and Lloyd-Hughes, 2014; Wheater and Gober, 2015). The intensity, frequency and magnitude of extreme climate events such as extreme precipitation, droughts, heat waves and cold waves associated with global warming are likely to change over space and time (Sheffield et al., 2012; Kharin et al., 2013; Stoner et al., 2013; Fischer and Knutti, 2014; Jeong et al., 2014,2015). As the increased variability in the mean and extreme climate events directly affects socio-economic and environmental sectors, projections of changes in the characteristics of these events are important to inform climate change mitigation- and adaptation-related decision making.

Earth System Models (ESMs) and their precursor Atmospheric Ocean General Circulation Models are regarded as the most credible tools to simulate time series of climatic variables at the global scale, accounting for the effects of rising GHGs in the atmosphere. However, there exist many fundamental challenges in the application of ESM outputs at local scales primarily due to the coarse resolution which is typically of the order of a few hundred kilometres (Khan et al., 2006; Fowler et al., 2007). Consequently, these models are unable to resolve important sub-grid scale features such as topography, clouds, and land use which influence climate variability at local to regional scales (Xu, 1999; Chiew et al., 2010). Therefore, the outputs of ESMs cannot at the moment be directly used for local scale climate impact investigations which generally require climatic data at certain points of interest in space (Bates et al., 1998; Fu et al., 2013). To overcome these limitations, downscaling techniques both dynamical and statistical have been developed to transform the ESM outputs to fine resolution information at local scales (Wilby and Wigley, 1997).

The dynamical downscaling techniques use Regional Climate Models (RCMs) to predict finer scale regional climate variables using boundary conditions from an ESM (Fowler et al., 2007). Although these models are capable of producing spatially distributed climatic predictions over smaller regions of interest (e.g., Wang et al., 2015), direct application of outputs from RCMs for climate change impact studies is still limited, perhaps due to their complicated design, high computational cost and/or bias partly originating from the driving ESM. Compared to the dynamical downscaling approach, statistical downscaling (SD) is based on establishing empirical relationships between large scale predictors which are assumed to be skilfully simulated by the ESMs and the target local scale variables (predictands) under the so-called *perfect prog* (PP) approach. Using this approach, reanalysis outputs for a representative historical period are used as predictors while simultaneous local scale observations are used as predictands for model calibration. The optimally calibrated model obtained using these observed data is applied to the output of different ESM scenario runs to obtain future projections of climate change. However, statistical downscaling is affected by some well-known limiting factors which are particularly relevant when applying it to the ESM scenario outputs (Wilby et al., 2004): the predictors are variables of relevance realistically simulated by the ESMs and they fully capture the climate change signal, and the transfer function is valid under climate change conditions.

In general, statistical downscaling approaches have been grouped under three broad categories: regression-based methods, weather typing approaches, and stochastic weather generators (WGs). A comprehensive review on the strengths and weaknesses of each approach can be found in Xu (1999), Wilby et al. (2004) and Fowler et al. (2007). The SD approach implemented in the current study is based on WGs. Asong et al. (2016; hereafter denoted as A16) provided an in-depth review of existing WGs and placed Generalized Linear Models (GLMs) as well as their limitations within the context of multisite multivariate modelling as compared to other WGs. The major limitation of most WGs is that they concentrate on individual sites and therefore are unable to represent the spatial structure of the observed climatic variables. For many water resources design projects, particularly in large river basins, it is important to model simultaneous sequences of multiple variables (e.g., precipitation and temperature) over large heterogeneous areas, while maintaining physically plausible spatial, temporal and intervariable relationships. GLMs provide a flexible and unifying framework for accomplishing such challenging tasks.

The main aim of this study is to explore the suitability of the GLM framework for downscaling future climate change projections of precipitation and temperature sequences over the Alberta, Saskatchewan and Manitoba provinces of Canada, a region consisting of 47 diverse watersheds including the Saskatchewan, Athabasca, Peace, and Churchill River basins. This region was hard-hit by recurrent severe droughts in 1988, and 1999–2005, and floods in 2010, 2011, 2013, and 2014. Specifically, the study seeks to investigate the ability of GLMs to reproduce both the mean and extreme states of selected climatic variables in a changing climate. Given the projected global changes in climate for the 21st century, a deeper understanding of the impacts of climate change on local to catchment and regional scales is important for regional water resources management-related decision making and planning for future droughts and floods. The aim and specific objective are achieved through the following steps: (1) The National Center for Environmental Prediction (NCEP) Reanalysis-I dataset (Kalnay et al., 1996) is used to train the GLM framework; (2) then by constraining ESM outputs on the NCEP-based GLM parameters, future projections of precipitation and temperature sequences are generated.

This paper is organized as follows: Section 2 provides a brief description of the study site and materials used in the study. Section 3 describes the generic methodology for downscaling ESM outputs to station scales. Results of the study are presented in Section 4 while a discussion of the results within the general scientific context is provided in Section 5. The study is summarized and concluded in Section 6.

2. Study site and materials

2.1. Study site

The study area comprises the Canadian Prairie Provinces of Alberta, Saskatchewan and Manitoba (Fig. 1), with a total surface