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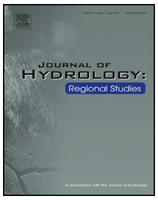

Hydrological response to dynamical downscaling of climate model outputs: A case study for western and eastern snowmelt-dominated Canada catchments

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ABSTRACT

Study region: An analysis of hydrological response to a dynamically downscaled multi-member multi-model global climate model (GCM) ensemble of simulations based on the Canadian Regional Climate Model (CRCM) is presented for three snowmelt-dominated basins in Canada. The basins are situated in the western mountainous (British Columbia) and eastern level (Quebec) regions in Canada, providing comprehensive experiments to validate the CRCM over various topographic features.

Study focus: The evaluation of the CRCM as a tool to improve GCM simulations of catchment scale hydrology is investigated within the bounds of uncertainty associated with RCM simulations. Daily climate variables were extracted from a 30-year CRCM and GCM ensemble simulations. The hydrological response was assessed through the comparison of catchment water components simulated by SWAT.

New hydrological insights for the region: Results show that the CRCM captures the primary features of observed climate, but there are significant biases. Most noteworthy are a positive bias in precipitation and a negative bias in temperature over the BC basin. When looking at the hydrological modeling results, the benefit of using the RCM *versus* GCMs emerged distinctly for the mountainous BC basin where the RCM is preferred over the GCMs. The sensitivity experiments show that uncertainty in the GCM/RCM's internal variability must be assessed to provide suitable regional hydrological responses to climate change.

1. Introduction

The economic value of freshwater in Canada makes this resource one of the highest-priority issues with respect to the impact of and adaptation to climate change. While climate change is an inherently global issue, impacts on water resources will vary at regional and local scales. Preserving these natural resources will require complex trade-offs to deal with regional economic, social and environmental issues related to water across the country. This is particularly challenging in Canada since its large geographic, climatic and hydro-ecologic diversity means that the projected effects of climate change on water resources can be expected to vary significantly across the country. In addition to nation-wide challenges for adaptation to

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climate change, Canada already experiences water-related problems linked to extreme hydrologic events and associated water quality issues (Warren et al., 2004). Spring snowmelt-driven flows are the major flood-producing mechanism in many Canadian watersheds (Simonovic and Li, 2003; Cunderlik and Ouarda, 2009). The spring snowmelt-driven flows also provide most of the surface water for many regions (Shrestha et al., 2012a,b). A disturbance of the hydrologic regime in snow-dominated regions in Canada could result in regional water shortages since built storage capacity could be inadequate to cope with streamflow seasonal shifts. Since water in both British Columbia and Quebec is already under mounting socio-economic pressure, the potential effects of climate change on overall availability of water has stimulated research efforts to develop appropriate water management tools to support regional management decisions.

The most comprehensive approach to studying climate change impacts on water management combines global climate models (GCMs) outputs with hydrological models. However, hydrological modeling depends on reliable information about relevant variables and their distribution in time and space from the regional to the local scale to ensure accurate simulations of streamflow trends for the past and present, and to make realistic predictions of future climate scenarios. However, GCMs are limited in their ability to represent fine-scale climate processes (Duffy et al., 2003), and may overlook important physical processes governing regional climate variability, especially over watersheds with complex topography (Xu, 1999; Arora, 2001; Diffenbaugh et al., 2005). Dynamical downscaling is a physically consistent approach to overcome this scale mismatch. In dynamical downscaling, a higher-resolution regional climate model (RCM) is driven by a GCM which provides the RCM with its boundary conditions. Due to their higher resolution, and to a dedicated physics adapted to this resolution, RCMs can improve simulations of climate variables (Hagemann et al., 2009; Maraun et al., 2010). Various worldwide initiatives (CORDEX, Giorgi et al., 2009 North America – NARCCAP, Mearns et al., 2009 Europe – PRUDENCE, Christensen et al., 2002 and ENSEMBLES, van der Linden and Mitchell, 2009; South America – CREAS, Marengo and Ambrizzi, 2006 and Asia – RMIP, Fu et al., 2005) have produced and continue to regularly produce ensembles of RCM simulations to serve the community of scientists studying climate change impacts.

Despite substantial efforts to enhance the spatial resolution of regional climate models in recent years, the additional information provided by RCMs for hydrological applications (which is often referred to as “added value”) has yet to be thoroughly evaluated (Hay et al., 2002; Freser et al., 2011). Many studies have demonstrated that RCMs can realistically simulate fine-scale climate features and climate statistics in comparison to observations (Semmler and Jacob, 2004; Früh et al., 2010; Kunz et al., 2010), and by extension, are somewhat successful in representing historical flows (Hay and Clark, 2003; Wood et al., 2004). However, they only use RCM outputs and implicitly assume that these outputs are superior to the driving GCM data, even though this is not explicitly demonstrated. Moreover, RCM simulations may add specific uncertainties tied to the model configuration (e.g., choice of driving GCM, choice of domains, regional model imperfections, etc.). Besides the problem related to partitioning bias sources in RCM outputs (i.e., boundary conditions or regional model errors), one of the most pertinent issues for hydrological applications is whether the magnitude of such troublesome biases in the GCM–RCM model chain is lower than that of biases already found in the GCM. If anything, the confidence placed in RCM simulations remains questionable in many hydrology-related studies.

The present study focuses on the evaluation of the RCM as a tool to improve GCM simulations for hydrological applications. Assessment of the benefits of the RCM is conducted for climate simulations of catchment scale hydrology, when the hydro-climate model chain is applied over three seasonally snow-covered catchments in both mountainous and leveled regions in Canada. The value of regional climate modeling is determined by evaluating the success of the RCM in reproducing present-day climate characteristics, along with the simulation of dominant components of the catchment water balance. The streamflow sensitivity to various sources of uncertainties associated with generating present-day regional climate simulations is also analysed with the prospect of providing additional insight into the reliability of an RCM for hydrological applications. More specifically, the derivated estimates of uncertainty in climate models are discussed with regards to winter and summer flows as well as annual extreme floods, based on our specific interest of snowmelt processes which dominate the hydrologic regime of the catchments under investigation.

Daily precipitation and temperature time series are derived from two ensembles of simulations from the Canadian Regional Climate Model version 4.3 (CRCM; Music and Caya, 2007) and two associated GCM ensemble simulations (the Canadian CGCM3 and the German ECHAM5) that are used to force the CRCM. CRCM and GCM climate variables are then used as input to the process-based Soil Water Assessment Tool (SWAT) model (Arnold et al., 1998) to simulate the catchments' hydrology over the 1971–2000 period. Since the hydrological response of a catchment results from the integration of the regional climate (in time and space), the results presented here provide comparison of the realism of the CRCM driven hydro-climatic response with those of the parent GCMs for two widely different snowmelt-dominated regions of Canada.

Section 2 describes sources of uncertainty associated with generating regional climate information when using a chain of climate models. Section 3 presents the study area and the ensembles of the CRCM and the two GCMs used in this study. A description of the SWAT hydrological model is given in Section 4. The relevant results of the evaluation of the added value of the RCM against that of the GCMs are analyzed in Section 5. The streamflow's sensitivity to uncertainties in regional climate simulations is presented and discussed in Section 6. Concluding remarks appear in Section 7.

2. Sources of uncertainty in the generation of regional climate information

RCM simulations are subject to various sources of uncertainty stemming from model structure and nesting configuration, and also from the natural variability of the climate system.