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Regional climate change trends and uncertainty analysis using extreme indices: A case study of Hamilton, Canada

Tara Razavi [a,c,*], Harris Switzman [b,1], Altaf Arain [c], Paulin Coulibaly [a,c]

[a] McMaster University, Department of Civil Engineering, 1280 Main Street West, Hamilton, Ontario L8S 4L7, Canada
[b] Ontario Climate Consortium/Toronto and Region Conservation, Toronto, Ontario, Canada
[c] McMaster University, School of Geography and Earth Sciences, 1280 Main Street West, Hamilton, Ontario L8S 4L7, Canada

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A B S T R A C T

This study aims to provide a deeper understanding of the level of uncertainty associated with the development of extreme weather frequency and intensity indices at the local scale. Several different global climate models, downscaling methods, and emission scenarios were used to develop extreme temperature and precipitation indices at the local scale in the Hamilton region, Ontario, Canada. Uncertainty associated with historical and future trends in extreme indices and future climate projections were also analyzed using daily precipitation and temperature time series and their extreme indices, calculated from gridded daily observed climate data along with and projections from dynamically downscaled datasets of CanRCM4 and PRECIS, and the statistically downscaled CIMP5 ensemble. A bias correction technique was applied to all raw daily temperature and precipitation time series prior to calculation of the indices.

All climate models predicted increasing trends for extreme temperature indices, maximum 1-day and 5-day precipitation (RX1day and RX5day), total wet day precipitation (PRCPTOT), very heavy precipitation days (R20mm), Summer Days (SU), and Tropical Nights (TR) and decreasing trend for Forest Days (FD) and Ice Days (ID) in 2020s, 2050s, and 2080s compared to present. CanRCM4 model did consistently project values in the upper range of the CMIP5 ensemble while the PRECIS ensemble was more in-line with the CMIP5 mean values. This difference may however be a function of different emission scenarios used.

1. Introduction

Characterizations of historical and future trends in climate, along with their uncertainty are frequently used at the local-scale to understand of how climate change influences the frequency and intensity of extreme weather. This information is regarded as critical to assessing and developing strategies for managing and mitigating the impacts of climate change on local communities (IPCC, 2012). Many climate change impact assessment and risk management tools recommend that decision makers employ some form of quantitative downscaled climate projection in order to characterize changes in the frequency and intensity of extreme weather events for various future time horizons relevant to the business areas in

* Corresponding author.
E-mail address: razaviz@mcmaster.ca (T. Razavi).
[1] Currently with WaterSMART Solutions Ltd.

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question (Engineers Canada, 2015; Field et al., 2014; ICLEI, 2010; IPCC, 2012; PNW Tribal Climate Change Project, 2013; Swanston and Janowiak, 2012). These estimates can be used in ''top-down'' or ''bottom-up'' climate change assessment and response frameworks (Bhave et al., 2014; Brown and Wilby, 2012; Brown et al., 2012; Wilby et al., 2014) and relied upon heavily in the development of the ''probability'' or ''likelihood'' within a typical risk score used in adaptation decision making (e.g., Engineers Canada PIEVC). The characterization of trends and uncertainty in climate extremes is also useful in the derivation of time series for input to process models used in wide array of planning and management sectors, such as the hydrologic models used in flood risk management (e.g., Seidou et al., 2012; Wilby and Keenan, 2012), ecological impact models (e.g., Baró et al., 2014; Candau and Fleming, 2011; Matthews et al., 2014), water allocation and source protection (EBNFLO Environmental and AquaResource Inc., 2010; Pasini et al., 2012; Zhou et al., 2010), and crop yield models (e.g., Kang et al., 2009), to name a few. As such, having a sense of how strongly we may detect these trends despite uncertainty associated with climate model outputs is critical for developing reliable decision support tools.

Despite the importance of having information on future climate trends, there is no definitive guidance, for Canadian jurisdictions in particular, on which datasets, downscaling methods and extreme indices may be used. Charron (2014) provides some guidance on the types of datasets available, but individual users are still faced with the challenge of selecting the specific datasets and indices to use in their planning processes. Extreme indices also tend to exhibit greater uncertainty than averages (Yao et al., 2013), and this adds an additional challenge to the development of information for use in climate change assessment and planning.

The ensemble approach to climate model analysis is widely recognized as being a reliable and efficient way of elucidating local trends associated with climate change while also characterizing uncertainties associated with projecting future climate, particularly for use in hydrologic modeling (Honti et al., 2014; Velázquez et al., 2012). There are however, many possible ways of constructing an ensemble of future climates that captures the full range of uncertainty associated with greenhouse gas emission scenarios, global circulation model (GCM), and downscaling methods. Each of these potential elements within an ensemble (e.g., emission scenario, GCM, and downscaling) greatly influences the outcome of an individual time series, which might also vary by location and time horizon of interest. To effectively assess future climate trends in light of this uncertainty, it is often advised that users construct and analyse an ensemble that incorporates data from a range of GCMs, downscaling methods, and emission scenarios (EBNFLO and AquaResource, 2010; IPCC, 2014).

Utilization of ensemble or multi-model datasets for future climate projections has the advantage of capturing full range of possible climate change scenarios. It also has the advantage of accounting for minimizing the effect of possible biases associated with individual models and can therefore provide the user with the most robust analysis of overall trends in climate (IPCC-TGICA, 2007; Tebaldi and Knutti, 2007). Such an analysis ensemble enables a robust assessment or projection uncertainty, considering the variability in the global climate models, downscaling methods, and emission scenarios.

The purpose of this study is to illustrate the level of uncertainty associated with trend analysis on extreme weather frequency and intensity indices at the local scale to determine if reliable trends can be detected, and if so what are their ranges. This analysis was applied to a study area in Hamilton, Ontario and results will be useful in defining the nature of future climate conditions in the local scale in the region. A range of possible future greenhouse gas emission scenarios and uncertainties associated with producing localized climate projections based on downscaled global climate model projections were prepared. This information could provide a comprehensive picture of future climate trends and uncertainty that could be used as a ''likelihood'' factor within climate change assessments locally. This analysis can also provide valuable information to help guide the development of scenarios for use in process-based hydrological modeling studies in the region.

To achieve the stated goals of this study, the spatial and temporal trends in historical climate data in Hamilton and surrounding area were analyzed. An ensemble of future climate projections of temperature and precipitation in the region was constructed to analyse the trend and uncertainty of future climate projections using extreme climate indices. An ensemble of different climate model datasets was compiled and then compared with trends in extreme temperature and precipitation indices. Extreme indices of climate have been analyzed in another studies such as (Powell and Keim, 2015; Donat et al., 2014; Sillmann et al., 2013; Yao et al., 2013; Bürger et al., 2012; dos Santos et al., 2011; etc.). The general approach in these studies was to compare historical observed trends with modelled historical trends using statistical test and graphical analysis in order to evaluate the model datasets. The focus of the current study is similar, however a more localized scale is examined and there is an emphasis on comparison of multiple different downscaled datasets. Validation of each downscaled dataset independently to the observed records in terms of ability to replicate statistical properties is a part of this comparison, but equally important was understanding how these various downscaled datasets compare relative to one another in the future. Currently, no such comparison is available in the literature at the local scale in the Hamilton region in Ontario.

2. Study area

The study area is centered on the City of Hamilton, located in southern Ontario, Canada at the western extent of Lake Ontario. The geographic area analyzed for this research is the municipal boundary of the City of Hamilton, plus a 10 km buffer which includes the full jurisdiction of the Hamilton Conservation Authority (Fig. 1). Annual precipitation varies between 750 and 900 mm. In the northern regions, the average air temperature ranges approximately between −7 °C (in January) and 19 °C (in July); and in the lake and southern regions, it ranges between −3 °C (in January) and 21 °C (in July). Major physiographic features influencing the local climate are Hamilton Harbour, marking the northern limit of the city, and