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Editorial

Special Issue: Past and Future Trends and Variability in Hydro-Climatic Processes

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1. Introduction

The earth has vast amounts of surface and sub-surface freshwater in the form of lakes, reservoirs, rivers, wetlands, soil water, groundwater, as well as water stored in snowpacks, glaciers, and permafrost. This freshwater is fundamental to the natural environment and for many social and economic activities, often referred to as ecosystem services, and considered in environmental flow frameworks [1]. The amount and timing of freshwater availability is primarily governed by processes and interactions within different components of the water cycle and are influenced by several natural factors including size of the watershed; type of landforms; storage characteristics (on the surface and in subsurface soil); type, rate, and amount of precipitation; presence of ice; amount and type of vegetation; soil properties (including permafrost); and evaporation. Human influence on water management, including dams, reservoirs, diversions, and water withdrawals, has also become an important component of the water cycle. Each of these acts on a variety of scales in time and space.

Considerable work has been carried out assessing past and projected future hydro-climatic changes (including extreme events) on various aspects of the water cycle across the globe. There is a general consensus that increasing temperatures and changes and/or variability in precipitation have altered the magnitude and timing of freshwater availability throughout the world. The changes were more pronounced in colder regions, which have been associated with dramatic decreases in cryospheric components of the water cycle (snow, ice, permafrost) e.g., [2]. These changes are projected to continue and intensify, particularly toward the end of this century under higher greenhouse gas emission scenarios e.g., [2–4]. However, a considerable range in results were identified, thus necessitating additional research aimed toward reducing uncertainty in projecting future freshwater availability, particularly at local/regional to national scales.

This special issue comprises a collection of nine papers (summarized below) focusing on various aspects related to past trends and variability and projected future changes in hydro-climatic processes that affect freshwater availability on local, regional, and/or larger scales, (with a particular focus on the cold-region country of Canada). These include large-scale reviews of current tools used for environmental flow determination, and issues related to the better understanding of continental-scale freshwater availability across Canada, both in the context of a changing climate. Another large-scale analysis involves the effects of climatic drivers on the spring freshet of major Arctic rivers across the circum-polar North. The important aspect of changing hydro-climatic extremes is addressed in studies examining projected changes to flood-generating mechanisms associated with snowmelt across Canada, and historical and projected changes to severe Canadian Prairie droughts. Western Canada is an area where past and projected future hydro-climatic changes are especially prominent e.g., [5,6] and this special issue contains two papers related to past and future changes to snowmelt-related variables in this region. Finally, the assessment of past and future hydro-climatic changes requires the best available observational and modelling data. As such, this special issue also includes investigations exploring the influences of climate change projections from multiple global climate models (GCMs) and different downscaling methods in various climate zones within China, and evaluating GCM-projected temperature means and extremes GCMs from the recent Coupled Model Intercomparison Project Phase 6 (CMIP6) across the diverse ecoregions of Alberta, Canada.

2. Summary of This Special Issue

This special issue includes two invited critical reviews related to hydro-climatic processes associated with freshwater availability. Firstly, St-Hilaire et al. [7] present how environmental flows (i.e., the amount of water required to sustain freshwater aquatic ecosystems) should be assessed in the context of a changing climate. They argue that three flow characteristics, namely quantity, timing, and quality, need to be minimally maintained for adequate environmental flows. The challenges with some of the current tools used for environmental flow determination are highlighted, including potential challenges and limitations in the context of climate change and associated non-stationarity. They conclude that classical techniques, especially hydrological methods, will require adaptations, e.g., definitions that include timing and quality of flows. It is recommended that the addition of at least one relatively simple water quality variable, (e.g., temperature) would be an important step forward for assisting regulators and practitioners in providing a more complete assessment of climate-change impacts on the aquatic ecosystems.

In a second review, Stadnyk and Déry [8] assess pan-Canadian hydrology under a changing climate. They emphasize that Canada, like other high latitude cold regions, is experiencing some of the most accelerated and intense warming resulting from global climate change. This has been associated with intensification of wet and dry hydro-climatic cycles, which is altering the spatial and seasonal distribution of surface waters across the country. The anticipated impacts to freshwater availability from climate change and anthropogenic regulation are reviewed in the context of continental and regional-scale prediction and subsequent decision making. The authors conclude that due to the size and complexity of Canada's drainage basins, and the paucity of observational networks, continued and future diagnosing and tracking of hydrologic change and future freshwater supply requires the implementation of continental-scale prediction models. These models should produce system-wide integrated outputs (e.g., streamflow simulations with water temperature and other water quality variables) and integrate dynamic climate-driven changes in freshwater discharge into ocean models, water quality models, and trophic structure models. This integrated modelling has a significant role to play in supporting Canada's Indigenous People with their community health and well-being.

The amount and timing of freshwater inflow to the Arctic Ocean plays a critical role in the global hydrological cycle, while changes in this freshwater budget can alter mechanisms of freshwater export with resulting impacts on the thermohaline circulation and resultant global climate. Freshwater is delivered to the Arctic via terrestrial river runoff, with the majority being released during the spring freshet. Ahmed et al. [9] examine the large-scale atmospheric and surface climatic conditions affecting the magnitude, timing, and regional variability of the spring freshets within sub-basins of the four largest Arctic-draining watersheds. Results reveal that climatic variations closely match the observed regional trends of increasing cold-season flows and earlier freshets. Flow regulation appears to suppress the effects of climatic drivers on freshet volume but does not have a significant impact on the timing of peak freshet flow magnitude reaching the ocean. Spring freshet characteristics are also influenced by large-scale teleconnections including El Niño-Southern Oscillation, the Pacific Decadal Oscillation, and the North Atlantic Oscillation. The authors recommend that future research involve an integrated multivariable approach incorporating temperature, precipitation, and regulation in advanced hydraulic flow modelling, to aid in the understanding of flow regulation versus climate.

Hydro-climatic extremes such as floods and droughts have significant impacts on freshwater availability and are projected to increase in frequency as the result of climate change. In a pan-Canadian analysis, Teufel and Sushama [10] examine projected changes to flood-generating mechanisms in terms of the relative contribution of snowmelt and rainfall using an ensemble of transient climate change simulations from a regional climate model. Results show that under 2 °C of global warming, the relative contribution of snowmelt and rainfall to streamflow peaks remains close to that of the current climate, despite slightly increased rainfall contribution. In contrast, a high warming scenario leads to widespread increases in rainfall contribution and the emergence of hotspots of change in currently snowmelt-dominated regions across Canada. These contrasting projections highlight the importance of climate change mitigation and keeping warming below the 2 °C level. With respect to droughts, Bonsal et al. [11] assess historical and projected future changes to the stages (e.g., onset, growth, persistence, termination) and other characteristics of severe drought occurrence across the agricultural region of the Canadian Prairies. They find that for the most part, the overall duration and intensity of future severe drought conditions is projected to increase mainly due to longer persistence, while growth and retreat stages were generally shorter. Considerable variability exists among individual climate model projections, including their ability to simulate observed severe drought characteristics.

Changes in freshwater availability are particularly prominent in mountainous regions of the world where substantial changes to snow and ice have been significantly impacting the timing and amount of freshwater supply in downstream regions. The cordillera region of western Canada is no exception and in this special issue, Newton, et al. [12] and Siemens, et al. [13] examine various aspects of past and future changes to snowmelt-related parameters in this area. In the former, results indicate continued reductions in the duration of winter including earlier onset of above-freezing spring temperatures, with the greatest changes in the Prairie and Mountain ecozones. There will also be increases to winter precipitation with more rainfall and less snow available for spring melt. Furthermore, hydrologic regimes will likely be characterized by water resource deficits dominated by losses during summer months. The magnitude of these projected changes is dependent on the future emissions pathway. Siemens et al. [13] apply a degree-day snowmelt model and remotely sensed snow cover area data to simulate the current baseline and project future streamflow in the upper Athabasca River Basin in western Canada. Projected changes using output from several GCMs reveal a consistent pattern with substantial increases in May runoff, smaller increases over the winter months, and decreased runoff in the summer months (June–August). Results from both of these studies demonstrate climatic warming impacts on freshwater availability (timing and amount) in mountainous and downstream regions. These findings can be used to inform adaptation strategies, water resource management, and environmental monitoring programs.

Finally, there are numerous observed and modelled datasets available for the assessment of past and future hydro-climatic changes. Each have pros and cons, and are continually being updated. It is therefore important that they be evaluated and tested for specific applications. To this end, Lun et al. [14] examine the discrepancies in multi-GCM climate projections using different downscaling methods across two river basins representing the north arid and south humid regions of China. Results show that the choice of downscaling method leads to differences in projections depending on the region and variable. They conclude that the selection of appropriate GCMs and downscaling methods for specific climate zones with different meteorological features require consideration to properly understand regional climate change impacts. Recently, updated CMIP6 GCM projections have become available and Masud et al. [15] evaluate their ability in simulating historical means and extremes of daily precipitation and maximum/minimum temperature across the diverse ecoregions of Alberta, Canada. The authors determine that each of the GCMs display varying degrees of accuracy depending on the sub-region and variable characteristics (e.g., means or tails of the distribution). The information gained from this analysis lays the foundation for future climate impacts analyses in similar regions using CMIP6 simulations.

3. Conclusions

Global warming has, and will continue to alter the amount and timing of freshwater resources across the world. These impacts are especially prominent in colder regions, mainly due to the rapid disappearance of snow and ice, as well as degradation of permafrost. It is also anticipated that hydro-climatic extremes, such as droughts and floods, will intensify these impacts. Even though there is high confidence in the direction of these changes, additional research is required to better quantify these impacts, particularly at the watershed scale. This should be carried out for various future greenhouse gas emission scenarios/warming thresholds using the best available data.

This special issue covers a wide range of contemporary topics related to hydro-climatic trends and variability and associated implications to freshwater availability. These range from continental-scale reviews to regional/watershed-scale analyses including data assessment studies. The results provide critical information toward the better understanding of past and future hydro-climatic trends and variability and it is recommended that this research continue using the best available observations, modelling procedures, and analytical techniques. This information is critical toward informing potential adaptation strategies, assisting in water resource management, and designing future environmental monitoring programs.

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