


Extreme Floods and Droughts under Future Climate Scenarios

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Abstract: Climate projections indicate that in many regions of the world the risk of increased flooding or more severe droughts will be higher in the future. To account for these trends, hydrologists search for the best planning and management measures in an increasingly complex and uncertain environment. The collection of manuscripts in this Special Issue quantifies the changes in projected hydroclimatic extremes and their impacts using a suite of innovative approaches applied to regions in North America, Asia, and Europe. To reduce the uncertainty and warrant the applicability of the research on projections of future floods and droughts, their continued development and testing using newly acquired observational data are critical.

Keywords: climate change; climate projections; extreme rainfall; floods; droughts

1. Introduction

The purpose of this Special Issue is to highlight several innovative manuscripts with a focus on projected hydroclimatic extremes and their impacts. Special attention was given to manuscripts quantifying projected changes in extreme precipitation and droughts, floods, and water quality parameters.

In many geographic regions, the effects of climate change on hydrologic systems are projected to be significant. Determining those regions and the direction and magnitude of changes is critical for long-term water management and planning decisions. Additionally, these decisions require the accuracy of projections that are often based on limited data and numerical models with large uncertainties. Complexities in the hydroclimatic processes, however, make estimating aggregate uncertainties surrounding projections of historical and future climate variability and change difficult and challenging. Characterizing changes in extreme events, such as temperature and precipitation extremes, floods, and droughts, is particularly difficult on account of small sample sizes and relatively short observational records. In addition, variability in large-scale dynamics and teleconnections may influence regional temperature and precipitation extremes across different climate model ensembles [1,2] because of differences in resolution, model structure, and the representation of teleconnections between ocean temperature, polar sea ice, and mid-latitude jet stream variability [3]. Even with these uncertainties, we observe robust changes in key climate variables related to floods and droughts, including increases in extreme warm temperatures globally and regional changes in the distributions of heavy precipitation events [4,5]. Changes in extremes over time are not solely due to shifts in the means of the distributions; they can also be associated with changes in shape and skewness related to the tails/extremes. Changes in sequencing and compound extreme events (e.g., drought combined with a heatwave) pose additional risks that are not well quantified in observations and models [6]. Special emphasis needs to be given to increasing modeling accuracy and proper determination of the confidence in the results. Continuous monitoring of climatic variables, the refinement of climate models, and the development of statistical/stochastic methods will be key components in more accurately determining the effects of climate change on hydrologic and climatic extremes.

2. Summary of the Papers in the Special Issue

The papers in this Special Issue are well-balanced in terms of their focus, ranging from heavy precipitation and floods to droughts and water quality. The papers also cover a wide range of climates and geographic regions, including Canada, the USA, Poland, and China.

Two papers [7,8] address heavy precipitation. In [7], the authors evaluate the applicability of the spatial analog as an alternative approach in extreme precipitation analysis using data from the central USA. They also highlight the existence of large uncertainties in studying climate projections and the need to minimize them in the future. In another paper [8], a comparative analysis of four downscaled data sets shows that a newly designed, novel statistical downscaling data set favorably compared with other commonly used data sets when applied to extreme rainfall analysis. This research also determined the magnitude of the projected increase in heavy precipitation in the Northeastern USA. For example, they determined that the event with a recurrence interval of 100 years today will have a 19- to 25-year recurrence interval in the late 21st century, depending on the climate scenarios.

A majority of the Special Issue authors presented their research dealing with projected streamflow extremes in various rivers around the world [9–12]. The projected streamflow characteristics, including frequency and timing of future flooding in Canada, were calculated [9]. This paper determined the changes for all regions in the country and provided a comprehensive assessment of the uncertainties in their estimates. In a companion paper [10], the authors discuss the consequences of these changes on flow regulation infrastructures (FRI) in highly populated/urban areas. They found that flood management guidelines for some FRIs would have to be reassessed to make them resilient to increased flooding in the future. In a paper with a similar scope [11], CMIP5-based climate modeling data were applied to a hydrologic model to produce future streamflow ensembles for a watershed in Idaho, USA. These ensembles were a broader envelope of the historic data, but the results generally indicated that flash flooding will increase in the future. The effects of errors in riverine flow projections on the return period of projected annual maximum inundation areas were presented in [12]. This research was based on a distributed flow routing model, MIKE11, and its lumped-parameter emulator to illustrate this uncertainty using a watershed in Southern Poland.

Papers [13,14] reported research on droughts. Future droughts under a range of climate scenarios were examined in [13]. This research identified the season, direction, and magnitude of changes in the length of dry spells for different parts of the Southeast United States. The effects of droughts on both low flows and floods were reported in [14]. This paper presented a novel method to create a super-ensemble of future climate series, which was then used to derive flooding and drought indices. The results indicated a marginal increase in low flows and a small decrease in high flows on the South Nation Watershed located in Ontario, Canada.

The drought-flood abrupt alteration (DFAA) has been studied as an extreme hydrological phenomenon, which is particularly important in riverine nutrient loading [15]. The results show projected changes in DFAA in the Hetao area, China, highlighting the often-neglected, but critically important effects of climate variability and change on riverine water quality, and implying combined drainage and irrigation measures during crop growth seasons.

3. Reflection of Future Research

Due to climatic changes, the risk of hydroclimatic extremes will be different in the future in many geographic regions of the world. To better prepare for the changes, it is important to account for impacts at the regional-to-local scales. Climate projections are typically based upon observational data analysis, climate monitoring, and relatively coarse climate models. These products can be combined using statistical and dynamical downscaling techniques to provide climate information at finer spatial and temporal scales. The accuracy of model-based climate projects is typically assessed through comparisons with historical data. It is generally assumed that the historical accuracy of climate models is an indication of future performance, but more research is required to justify this assumption. Consequently, models with higher historical accuracy often receive higher weights in climate studies,

but more studies are needed to determine whether weighted or equal weights should be used, and, if so, how the weights should be defined, and what would be the benefit of weights. Climate model products are also inherently uncertain, since the models represent simplified versions of the real world. These uncertainties can be due to coarse model resolution, a lack of physics or necessary complexity, forcing uncertainties, structural model differences, and different representations of natural variability (e.g., internal model variability).

Recent climate downscaling techniques are capable of producing increasingly finer spatial and temporal resolutions for climatic variables. These products are typically finer-scale resolution than global models. For example, the NASA Earth Exchange (NEX) dynamically downscaled products, based on adjusting statistical moments in temperature and precipitation outputs from CMIP5 models, are formatted with 25 km horizontal grid resolution, whereas the global models are typically on the order of 1 to 2 degrees. These downscaled products can be used to reduce model biases based on the agreement with historical records, but it is not clear how the corrections may influence the uncertainty in future projections, particularly if the statistical moments are changing with time. These challenges are exacerbated when considering extreme events, given the relatively short observational record, inadequacies of the models to represent extremes, and uncertainties in how tail parameters are changing.

Extreme weather events can also be jointly affected by both the influence of global warming and internal variabilities, such as the El Niño Southern–Oscillation (ENSO), Atlantic Multidecadal Oscillation (AMO), and Pacific Decadal Oscillation (PDO). In many cases, the internal variability appeared as the major driving force [16].

Generally, two main approaches are used in studying the effects of climate change on the frequency of floods and droughts. One approach assumes two or more quasi-stationary time periods and treats each of them as stationary. The other approach expresses statistics (e.g., frequency distribution parameters) as a function of time. Both approaches have advantages and limitations. Site-specific non-stationary frequency analysis is prone to having large uncertainties. The distribution parameter estimates, e.g., the shape parameter of a frequently used generalized extreme value distribution, can be sensitive to large observations, resulting in very uncertain quantile estimates. This problem could be alleviated by limiting the parameter ranges, or by developing a regional analysis instead of point estimates. For any quasi-stationary approach, assuming stationarity for longer time periods is not realistic in a changing environment. On the other hand, using shorter time periods for statistical analysis [8,17,18] creates a problem with estimations of large recurrent events (e.g., 100-year event based on 20 years). Thus, the stationarity assumptions need to be evaluated in each case (e.g., the evaluation of the stationarity assumption for meteorological drought estimation in the contiguous US [19]).

For rainfall and runoff frequency analysis, the annual maximum series (AMS) and partial duration series (PDS) methods for frequency estimates are generally used. Typically, the results indicate that the AMS with Langbein's adjustment [20] would produce very similar results to those based on PDS, but this does not have to be true for projected extremes. An additional reason for using PDS instead of AMS could be the fact that the increases in precipitation frequency and magnitude are not correlated [21]. It would be very useful to validate the findings of the paper as new data become available.

Estimating confidence limits is possibly the most challenging task in the analysis of weather/climate extremes related to floods and drought. Many existing methods incorporate calculations of confidence intervals (CIs), but they tend to be overconfident and underestimate the true limits. For example, the L-moments approach creates CIs based on Monte Carlo resampling of statistical distribution parameters, but it ignores the uncertainty based on the distribution selection, data observations, their spatial/temporal aggregation, etc.

The propagation of uncertainties from the global climate to regional extremes also needs more attention, as well as the cross-auto-correlation structure of residuals, using hybrid approaches capable of synthesizing observations and models [22,23]. Coupled feedbacks and interactions between natural and human systems can also influence the occurrence and severity of extreme climate/weather events.

New multidisciplinary research and methodologies in areas related to extremes are broadly applicable to water planning and management, which can ultimately lead to improved optimum water system design and control in a changing environment.

Conflicts of Interest: The authors declare no conflict of interest.

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