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Future projections of extreme precipitation intensity-duration-frequency curves for climate adaptation planning in New York State

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ABSTRACT

A set of future extreme precipitation probabilities are developed for New York State based on different downscaling approaches and climate model projections. Based on nearly 50 downscaling method-climate model combinations, percent differences are computed between simulated extreme precipitation amounts for one historical (1970–1999) and three future (2010–2039, 2040–2069, and 2070–2099) time periods. These percent change factors are then applied to the observed extremes to estimate future precipitation extremes. The results are presented to users via an interactive website (http://ny-idf-projections.nrcc.cornell.edu). As the engineering community is the primary user, the website displays intensity-duration-frequency (IDF) graphs depicting the: 1) mean projected extreme precipitation intensity, 2) range of future model projections, 3) distribution of observed extreme precipitation intensities, 4) confidence intervals about the observed values.

One-hundred-year recurrence interval precipitation amounts exhibit a median increase of between 5 and 10% across the state in the 2010–2039 period regardless of greenhouse gas concentration. By the 2040–2069 period, the median increase is on the order of 10–20% for the high concentration case (RCP 8.5), but remains below 10% if concentrations are lower (RCP 4.5). At the end of the century, all downscaling method climate model combinations indicate increases, with a median change of between 20 and 30% in the case of high concentrations.

Practical Implications

In 2014, New York State (NYS) enacted the Community Risk and Resiliency Act (CRRA). This act requires applicants (e.g. local communities) as well as state agencies to consider future flood risk in planning and constructing public infrastructure. State agencies must also consider these hazards in funding or permitting decisions. Although CRRA mandates consideration of future climate risks, it offers no implementation guidance. Rather, CRRA requires the NYS Department of Environmental Conservation (DEC) to develop such guidance.In addition to sea-level rise, NYS views effective implementation of the CRRA as dependent on projections of future extreme precipitation frequency. Current design standards for hydrologic and transportation infrastructure, as well as public and environmental safety regulations, are based on historical precipitation recurrence probabilities. An underlying assumption of these extreme precipitation analyses has been the stationarity of the historical record. Recently the validity of this assumption has been called into question, as numerous studies have shown a significant increase in the frequency and magnitude of extreme precipitation across the northeastern United States since the mid-20th century.This work describes the development of a set of future precipitation recurrence probabilities for NYS using a set of nearly 50 downscaled climate model projections. Based on different statistical or dynamical downscaling approaches and different global climate models, percent differences were computed between simulated extreme precipitation amounts for one historical (1970–1999) and three future (2010–2039, 2040–2069, and 2070–2099) time periods. These percent change factors were then applied to the observed extremes to estimate future precipitation extremes. An ensemble mean value and range (10th–90th percentile) of future projections were obtained from the set of climate model-downscaling method combinations.An interactive website (http://ny-idf-projections.nrcc.cornell.edu) facilitates access of the results by the user community, with products tailored to both engineers and less technical users. Station-specific intensity-duration-frequency (IDF) graphs

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(Fig. 10) provide the data necessary for engineering applications to demonstrate consideration of future climate conditions. The IDF graphs present four key pieces of information: 1) mean projected extreme precipitation intensity in future time periods, 2) a measure of variability in the future model projections; 3) historical extreme precipitation statistics based on station data; and 4) confidence intervals illustrating the uncertainty inherent to historical values. This allows users to weigh the future changes relative to a range of equally plausible precipitation extremes based on historical data.Complementary map-based products offer non-technical users a cursory statewide view of the projected changes in extreme precipitation. The results show that continued increases in extreme precipitation are expected across NYS, with little spatial variability in the magnitude of percent change relative to historical precipitation extremes. In the early part of the 21st century, the average increase in recurrence interval precipitation amounts is typically 5–10% (Fig 6a) with considerable overlap between the historical confidence intervals and range of future model projections. By mid-century (2040–2069), increases are generally in the 10–20% range assuming continued high greenhouse gas concentrations (Fig 6b). The late-century (2070–2099) estimates show the most model-to-model variability with increases averaging between 15–25% (Fig. 6c), but exceeding 50% at some stations. By late century, precipitation intensities that currently have a 1% chance of occurring in any year are expected to occur at least twice as frequently across much of the state (Fig. 11).

1. Introduction

Extreme precipitation has important implications for urban and rural development, public infrastructure, watershed management, agriculture, and human health. Historical climate records indicate that the northeastern U.S. has experienced significant increases in extreme precipitation since the mid-to-late twentieth century (DeGaetano, 2009; Heineman, 2012; Kunkel et al., 1999; Kunkel, 2003). Moreover, the most recent assessment from the Intergovernmental Panel on Climate Change (IPCC, 2014) reports with likely confidence that the frequency and magnitude of extreme precipitation in this region will continue to increase throughout the twenty-first century. Such changes will exacerbate the societal impacts of extreme precipitation in the future.

The Northeast U.S. is not the only region that has been experiencing greater extreme precipitation frequency and magnitude. Similar trends are noted in the central U.S. (Groisman et al., 2012) as well as many other regions throughout the world (Groisman et al., 2005; Fischer and Knutti, 2016). Other measures of extreme precipitation, such as maximum 5-day accumulation and precipitation amount on extremely wet days, have also shown increasing trends in the U.S., Europe, and Australia (Janssen et al., 2014; Moberg and Coauthors, 2006; Alexander and Arblaster, 2009). Other recent examples in the literature demonstrate the extent to which extreme precipitation has increased from both regional (e.g. Scherrer et al., 2016; Limsakul and Singhruck, 2016) and global (e.g. Donat et al., 2016) perspectives. Coumou and Rahmstorf (2012) point to increases in atmospheric water vapor (consistent with increasing average temperature) and increases in the frequency of local convective storm events (also enhanced by warming surface temperatures) as physical reasons for these changes. However, in some regions, linkages to certain atmospheric circulation patterns have been posed as influencing changes in precipitation extremes (e.g. Kenyon and Hegerl, 2010). Climate model simulations suggest a continuation of these extreme precipitation trends through the 21st century (e.g. Donat et al., 2016; Ning et al., 2015; Sun et al., 2016).

Engineering design has long relied on statistical extreme value analysis of precipitation (Yarnell, 1935). Intensity duration frequency (IDF) curves typically serve as a conduit for translating precipitation to runoff volume, particularly in basins under 65 km^2. These curves specify precipitation intensity (mm hr^{-1}) as a function of storm duration and average return frequency.

An underlying assumption of traditional IDF analyses has been stationarity of the climate. Hence, it was expected that past conditions were an adequate guide to the future. However, given the many studies documenting observed and projected increases in extreme precipitation frequency, decision makers have begun to question this assumption and seek information regarding projected future extreme precipitation frequency. Most efforts to estimate future IDF information have been on a case-by-case basis, often at the city level. This is quite different from historical extreme precipitation analyses that have typically been published at broad national or regional scales (e.g. Perica et al., 2013). Likewise, existing IDF projections have been developed by a range of climate service providers ranging from government and academia to the private sector, as opposed to historical analyses that have been almost exclusively developed by government agencies and then applied to specific locations or projects by the consulting industry.

An example of city-level IDF projections (AMEC Environment Infrastructure, 2012) uses the generalized linear model approach of Towler et al. (2010) to estimate future IDF values for Welland, Ontario, Canada using climate model output as predictors. Relative to the existing Welland IDF curve that was compiled in 1963, they found that precipitation intensities on average decrease through 2050. Wang et al. (2015) developed projected IDF curves for other cities in Ontario, Canada, using dynamically downscaled precipitation data from a regional climate modeling system (PRECIS; Wilson et al., 2011) driven by an ensemble of Hadley Centre Coupled Model, version 3 (HadCM3) output. They found that projected 24-h 100-year precipitation amounts increased by about 25% from the historical base period to the 2080s. Rodríguez et al. (2014) used a statistical downscaling approach to investigate changes in IDF curves for Barcelona, Spain. They found projected increases in precipitation extremes of between 3 and 14% by the late 21st century for recurrence intervals ranging from 10 to 500 years.

This paper discusses a project designed to provide NYS with guidance regarding plausible future changes in extreme precipitation return frequency. One of the impetuses for this work is the Climate Risk and Resiliency Act (CRRA), which requires specific state permitting, funding and regulatory decisions to demonstrate that future climate risks associated with flooding (inland, storm surge and sea level rise) have been taken into account. Currently, approaches for addressing future flood risk are not well defined. Suggestions range from the use of the 1% annual flood elevation plus an additional 0.61 m (2 ft) of freeboard to the use of the 0.2% annual recurrence (500-yr) flood (Lowery, personal communication, 2016). NYS prefers a climate-informed science approach that relies on projections of future precipitation-intensity frequencies for different durations. This paper describes the approach used to achieve this goal including 1) evaluation of downscaling method–climate model combinations in replicating historical precipitation extremes, 2) application of downscaling methods to project precipitation extremes in future periods, 3) quantification of methodological and climate model uncertainties, and 4) dissemination of results to users via web-based tools.