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Research papers

Uncertainty of Intensity–Duration–Frequency (IDF) curves due to varied climate baseline periods

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ABSTRACT

Storm water management systems depend on Intensity–Duration–Frequency (IDF) curves as a standard design tool. However, due to climate change, the extreme precipitation quantiles represented by IDF curves will be subject to alteration over time. Currently, a common approach is to adopt a single benchmark period for bias correction, which is inadequate in deriving reliable future IDF curves. This study assesses the expected changes between the IDF curves of the current climate and those of a projected future climate and the uncertainties associated with such curves. To provide future IDF curves, daily precipitation data simulated by a 1-km regional climate model were temporally bias corrected by using eight reference periods with a fixed length of 30 years and a moving window of 5 years between the cases for the period 1950–2014. Then the bias-corrected data were further disaggregated into ensemble of 5-min series by using an algorithm which combines the Nonparametric Prediction (NPRED) model and the method of fragments (MoF) framework. The algorithm uses the radar data to resample the disaggregated future rainfall fragments conditioned to the daily rainfall and temperature data. The disaggregated data were then aggregated into different durations based on concentration time. The results suggest that uncertainty in the percentage of change in the projected rainfall compared to the rainfall in the current climate varies significantly depending on which of the eight reference periods are used for the bias correction. Both the maximum projection of rainfall intensity and the maximum change in future projections are affected by using different reference periods for different frequencies and durations. Such an important issue has been largely ignored by the engineering community and this study has shown the importance of including the uncertainty of benchmarking periods in bias-correcting future climate projections.

1. Introduction

The design of hydrosystems is commonly developed with the help of Intensity–Duration–Frequency (IDF) curves that represent the frequency and the intensity of maximum rainfall events in different durations. In different parts of the world, an upward trend in the maximum daily and sub-daily precipitation values has been observed, and these values are comparable to the amounts shown by the IDF curves (Al Mamoon et al., 2016; Rodríguez et al., 2014; Mirhosseini et al., 2014; Arnbjerg-Nielsen, 2012; Denault et al., 2002; Waters et al., 2003). However, non-stationarity causes variation over time in the return period of a specific rainfall event (i.e., storm) (Mailhot and Duchesne, 2010). It has been predicted that by the end of 21st century there will be a substantial reduction in the return period of an annual maximum precipitation amount with frequent occurrence of extreme rainfall events (Intergovernmental Panel on Climate Change (IPCC), 2012). The sensitivity of urban storm water collection systems could be adversely affected by such changes (Willems, 2013). In many cases, the design of such collection systems is based on historical IDF curves, but these curves may need to be modified to account for the possible effects of climate change (Watt and Marsalek, 2013). Therefore, urgent actions are needed to examine the accuracy and uncertainties of the IDF curves that are currently used for the design of urban storm water collection system taking into account projections of future short-duration rainfall (hourly or sub-hourly) under the impact of climate change.

To model the hydrological outcomes of urban watersheds reliably, whether for the current or future climate, it requires the use of hourly or even sub-hourly precipitation data (Segond et al., 2006; Watt et al., 2003). However, observed rainfall with fine temporal resolution is not often available; in many parts of the

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world, precipitation is generally recorded on a daily basis, and hourly records are available only in limited regions. In addition, most of the climate data are with daily temporal resolution. Hence, to assess the robustness and sensitivity of urban storm water drainage systems, it is necessary to disaggregate precipitation for the current climate (in case fine resolution is not available) and future climate into finer temporal resolutions. Moreover, the creation of future IDF curves that depend on finely tuned records of precipitation will be affected by different sources and levels of uncertainty. Such uncertainty casts considerable doubt on the outcome of the entire process, especially from an engineering and practical perspective. Some sources of uncertainty include the climate change scenarios, the adopted global climate models (GCM) and regional climate models (RCM), natural internal weather variability, methods of downscaling and disaggregation, and techniques of bias correction. Several authors suggest that uncertainty in the results might be mitigated by adopting an ensemble approach where consideration is given to more than one climate model, IPCC emission scenarios, and statistical downscaling methods (Van Der Linden and Mitchell, 2009; Taylor et al., 2012). In this way, it should be possible to assess the extent of the uncertainty associated with each of these approaches.

Much of the recent literature on future climate projections in general (Sarr et al., 2015; Sunyer et al., 2015) and future IDF curves specifically (Alam and Elshorbagy, 2015; Kuo et al., 2014; Rodríguez et al., 2014; Mirhosseini et al., 2013) has adopted the aforementioned suggestion and has used ensemble of climate models and IPCC emission scenarios to cover the uncertainty resulted from each of these two sources. However, with regards to the uncertainty caused by the bias correction of a climate model, we have noticed that most of the recent studies have carried out the bias correction of GCMs and RCMs statistically by depending upon one reference period (Sarr et al., 2015; Sunyer et al., 2015; Kuo et al., 2014; Mirhosseini et al., 2013). The problem with the bias correction studies so far lies in the assumption used for the correction. It assumes that the bias for the future period is identical to the bias in the control period, which may not always be true, and this may affect the results of future bias-corrected data. This is confirmed by Boberg and Christensen (2012) and Sunyer et al. (2014) who have shown that the bias of a climate variable (temperature or rainfall) depends on the value of that climate variable. Although some studies do account for a change in bias, they either for coarse spatial resolutions especially for GCMs (Li et al., 2010; Miao et al., 2016) or rely on subjective decisions that depend upon expert knowledge to define the range of bias change between the current and future climate (Buser et al., 2009, 2010).

The second drawback of many bias correction studies is related to the reference period used for the bias correction. This is confirmed by Li et al., 2010, who have shown that the sensitivity of bias correction results is related to the choice of various reference periods. The authors argue that care should be taken when adopting a specific reference period for bias correction.

A trend analysis of the rainfall process and its extremes shows that extreme precipitation exhibits multidecadal timescale fluctuations (Ntegeka and Willems, 2008; Willems, 2013). The precipitation oscillation peaks in different periods depending on the season and the region (Willems, 2013). Thus, choosing a reference period within an oscillation period of lower extremes could produce a different result for future climate compared with that based on another period. In addition, Willems (2013) shows that multidecadal oscillations occur with irregular periodicities in the range 30–60 years for central–western Europe. Thus, fixing the length of the reference period at 30 years in a bias correction might not reflect the true risk of precipitation in the future climate. However, as most of the regions lack long records of precipitation data for the study of the trend in rainfall extremes, researchers tend to adopt the results of Willems (2013) and fix the length of the reference period at 30 years for their climate studies (Buser et al., 2009, 2010; Sunyer et al., 2015; Kim et al., 2015, 2016).

As most of the recent studies on future climate projections adopt the above-mentioned conventional assumption for bias correction and fixed the length of the reference period at 30 years, we have adopted the same assumptions in our study. However, we use different reference periods to correct the future RCM data bias and build future IDF curves by using only one RCM and one method for bias correction. By doing this, the extent and source of the uncertainty in future IDF curves can be investigated. Yet, some uncertainty also arises from the reference period used for the bias correction of the RCM based on the conventional assumption of correction.

Most of the previous studies have adopted the period 1961–1990 as the reference period for the bias correction or the downscaling of future GCMs and RCMs (Yang et al., 2010; Dosio et al., 2012; Kim et al., 2015, 2016). However, it would be logical to assume that the most recent period is more likely to resemble future projections because it has experienced more warming (Li et al., 2010). Thus, we intend to ascertain which of the periods (e.g., the commonly used reference period (1961–1990), the most recent (1985–2014), or another specific reference period) produces the most extreme rainfall prediction. This is of importance for designing a reliable sewer system. Such a reference period with highest extremes may produce the worst consequences for the sewer system and thus should be considered in the decision making process. Although such a case may not be adopted for the design of the sewer system, due to the performance deterioration of any solution for the flood risk problem over time (Ashley et al., 2008), it is helpful to know what other flexible and sustainable solutions should be taken into account in flooding mitigation measures (Willems et al., 2012; Willems, 2013).

Thus, the objectives of this study are to (i) generate a continuous record of 5-min precipitation for the period 2069–2098 and construct future IDF curves; (ii) identify the change between the current and future climate; (iii) quantify the uncertainty associated with the constructed future IDF curves that may be caused by the reference period; and (iv) determine whether there is a specific reference period when used for the bias correction and that produces the more extreme values than the other reference periods, i.e., the worst case that the designer of a sewer system needs to know.

2. Study area and data

2.1. Rainfall data

The study area is located in West Yorkshire, Northern England and comprises an area of approximately 12 km × 5 km. The observed rainfall dataset used in this study is the gridded precipitation product, created by the Centre of Ecology & Hydrology Gridded Estimates of Areal Rainfall (CEH_GEAR) for the period 1890–2014 (Keller et al., 2015). This gridded data set has a spatial resolution of 1 km × 1 km and is based on different station densities for different periods. Station density peaked at around 6250 stations in 1974 (Eden, 2009), while for the period 1961–2000 there was an average of one rainfall station per 49 km^2 (4400 stations) (Perry and Hollis, 2005). For this study, the CEH rainfall data that cover our study area for the period 1950–2014 were adopted as the observed data.

The composite radar data covering the study area were provided by the UK Met Office radar network through the British Atmospheric Data Centre (BADC) with spatial and temporal resolutions of 1 km and 5 min, respectively. A 60-km^2 area of radar grids covers the study area. The catchment is within the coverage of